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STATUS OF AERIAL COLOR PHOTOGRAPHY IN GOVERNMENT AGENCIES

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SUMMARY

This report is a summation of research into the status of aerial color photography in the Government with specific reference to those areas related to Military Geographic Intelligence applications. Because of the rapidly moving state-of-the-art, 1 July 1967 was arbitrarily selected as the cutoff date for inclusion of information. Department of Defense activities were restricted to unclassified information for maximum dissemination of this report. The growing recognition of the utility of aerial color photography for studies in the fields of geology, geography, archaeology, landforms, range management, target detection, highway planning, and hydrology requires that information regarding this form of remote sensing be more widely distributed.

The report concludes that the state-of-the-art in aerial color photography is adequate for obtaining satisfactory military photographs provided cameras and emulsions are carefully selected for the mission.

FOREWORD

Authority for research and the preparation of this report is contained in Project 4A623501A854, "Military Geographic Intelligence."

The research information was gathered by and field tests were participated in by Abraham Anson, under the supervision of Bernard B. Scheps, Geographic Information Systems Branch, and Dr. Kenneth R. Kothe, Chief, Geographic Sciences Division.

The work was initiated at the suggestion of James E. Gillis, Jr., Associate Technical Director, and performed under the general direction of Gilbert G. Lorenz, Technical Director, U. S. Army Engineer Topographic Laboratories (formerly designated U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency).

The information presented here is in the form of a Technology Brief. The purpose of the Technology Brief series is to give timely dissemination to results of research and study. The data gathered in this study are highly perishable because of the rapid developments in this field.

CONTENTS

CONTENTS (cont'd)

ILLUSTRATIONS

ILLUSTRATIONS (cont'd)

TABLES

STATUS OF AERIAL COLOR PHOTOGRAPHY IN GOVERNMENT AGENCIES

I. INTRODUCTION

1. Requirement. A continuing requirement exists for more adequate and detailed information of man's environment, the land, the sea, and the atmosphere. In each area, interested Government agencies perform research and development for their own responsibilities and their own purposes. Remote sensing, which includes aerial photography, is employed by many Federal agencies to derive environmental information about the earth's surface. Inevitably, some duplication of effort occurs because the technology is the same though applications differ. The purpose of this report is to record some of the research, development, and uses of aerial color photography at the present time in various Government agencies.

2. Subject. The trend of history presupposes that similar ideas concerning a particular subject occur to many different individuals at the same time. This is the case with aerial color photography, which is now in process of being developed for greater use by many different elements of the Federal Government.

a. Scope. This report is concerned with the use of aerial color photography in the Federal agencies. Agencies which use aerial photography include the Interior Department, Commerce Department, Agriculture Department, Defense Department, and the National Aeronautics and Space Administration. A brief consideration of some important foreign development is included for balanced comparison.

b. Areas Investigated. Investigations have been made of the technology of aerial color photography, including emulsions, cameras, and processing equipment. Also, a study has been made of the application of aerial color photography to the specific requirements of each agency, such as mapping, resource evaluation, oceanography, terrain evaluation, and target location (Defense Department).

3. Background. In 1861, James Clerk Maxwell exhibited the world's first trichromatic color photograph during a lecture before the Royal Institution of London (1)* by superposing three dyed images produced

*Numbers in parentheses refer to entries in Literature Cited.

by photographing a colored ribbon separately through red, green, and blue filters. Maxwell invoked photography to demonstrate that a full spectrum of colors could be produced by using the light of three colors. Since that time, considerable progress has been made in reproducing the natural appearance of scenes through the photographic processes.

Aerial photography, as a means of recording the "bird's-eye" view, presents special problems. The invention of the stereoscope in 1838, by Sir Charles Wheatstone, preceded by 21 years the ascent of the first aerial photographer, Gaspard Felix Tournachon, who photographed the city of Paris in 1859 from a gas-filled balloon. The next logical step was the marriage of hardware and camera application, which resulted in the development of photogrammetry as it is today. Getting the bird's-eye view interposed a filtering layer of air, haze, dust, and sometimes clouds between the photographer and the subject.

Black and white photography was exposed successfully from airplanes almost from the time they were first operational, but color photography required longer exposures because of the three-layer emulsions; therefore, progress in aerial color photography awaited the development of faster emulsions and more precise chromatic correction.

It is an observable fact that aerial color photography of large areas with contrasting hue exposed at low altitude will record more successfully and be more easily interpreted than aerial color photographs taken at higher altitudes that register smaller areas, in which contrast had been diminished by the column of air containing haze and dust. Yet even poor aerial color photographs, which record a contrast in hue, will accurately depict more differences in terrain information than will a black and white photograph which records solely in shades of gray. This is partly because of having three information levels (red, green, and blue) to modulate and partly because of the greater visual ability to discriminate shades of color. Aerial color photography is not confined to color fidelity; aerial false color film, also known as camouflage detection film, will also discriminate terrain features in a manner such that a photointerpreter who knows the medium can interpret a scene accurately.

Aerial color photography has been employed successfully in low-altitude soils and agriculture surveys, and extremely high-altitude terrain surveys from spacecraft. Scientists and engineers interpret water resources from the long-range view; analyze urban patterns; study geology, geography, archaeology, landforms, range management, harbor development, and hydrology; plan highways; and interpret the effect of one

area of the earth upon another. The visual contrast offered by color photography yields more information than black and white photography with its limited number of shades of gray. Color photography employs more display channels to convey spectral and intensity information. Black and white recording confuses these two by assigning them to the same display channel.

II. TECHNOLOGY

4. Aerial Color Film. At the present time, several industries are manufacturing aerial color film on a world-wide basis; however, the Eastman Kodak Company and the General Aniline and Film Corporation are the two principal United States manufacturers (Table I).

a. Eastman Kodak Company. The Eastman Kodak Company, Rochester, New York, manufactures several types of aerial color films as follows:

(1) Ektachrome Infrared Aero Film, Type 8443, is a false color reversal film on triacetate base used for camouflage detection and the penetration of haze (2).

(2) Kodak Ektachrome MS Aerographic Film, Type 2448, is a medium-speed reversal film on an Estar base used for mapping and can also be processed as a negative (Figs. 1 and 2).

(3) Kodak Ektacolor Aerial Film, Type SO-276, is a color negative film on triacetate base for aerial photography at low altitudes (3).

(4) Kodak Ektachrome Aero Film, Type 8442, is a high-speed color reversal film on a triacetate base used for low-altitude reconnaissance (3).

(5) Kodak Ektachrome EF Aerographic Film, Type SO-397, is a high-speed reversal film on an Estar base (3).

b. General Aniline and Film Corporation. The General Aniline and Film Corporation, Binghamton, New York, manufactures several types of aerial color films as follows:

(1) Anscochrome D/100 Aerial Film is a medium-speed color reversal film designed to produce color positive transparencies

Table I. Characteristics of Aerial Color Films Used by Government Agencies

Film	Type	Sensitivity	Description	Base	Base Thickness (in.)	Aerial Exposure Index[a] [b]	RMS Granularity	T.O.C. 1000:1 Resolving Power	Development Chemistry
			Eastman Kodak						
Ektachrome Infrared Aero	8443	IR, COL	False Color Reversal (CD)	Triacetate	0.0052	10 w/W12 (100)	0.058	71	Kodak E-3 or EA-4
Ektachrome MS Aerographic	2448	COL	Medium-Speed Color Reversal Process as Negative (C)	Estar	0.0040	6 (100) (70)	0.039	75	Kodak EA-4 Kodak C-22 Modified
Ektacolor Aerial	SO-276	COL	Color Negative	Triacetate	0.0052	10 (100)	0.026	50	Kodak C-22
Ektachrome Aero	8442	COL	High-Speed Color Reversal for Low-Alt Recon	Triacetate	0.0052	25 (70)	0.030	56	Kodak E-3 or EA-4
Ektachrome EF Aerographic	SO-397	COL	High-Speed Reversal	Estar	0.0040	6 (70)	0.015	63	Kodak E-3 or EA-4
			General Aniline and Film						
Anscochrome D/100	D/100	COL	Medium-Speed Reversal	Gafstar (Estar)	0.0050	(100)	0.028	100	Ansco AR-1 or AR-2[d]
Anscochrome D/200	D/200	COL	High-Speed Reversal	Gafstar	0.0050	(160)	0.028	100	Ansco AR-1 or AR-2[d]
Anscochrome D/500	D/500	COL	High-Speed Reversal or Process as Negative[c]	Gafstar	0.0050	(300)	0.053	90	Ansco AR-1 or AR-2[d]

(a) Kodak indexes are used with Kodak Aerial Exposure Computer. Index is reciprocal of twice exposure at point on the toe of the characteristic curve where slope is 0.6 gamma.

(b) United States America Standards Institute (USASI) equivalent rating in parentheses.

(c) Processing as negative must be preplanned for EK MS, to obtain correct exposure; not required for D/500.

(d) Ansco AR-1 for high-speed processing or AR-2 for low-speed processing.

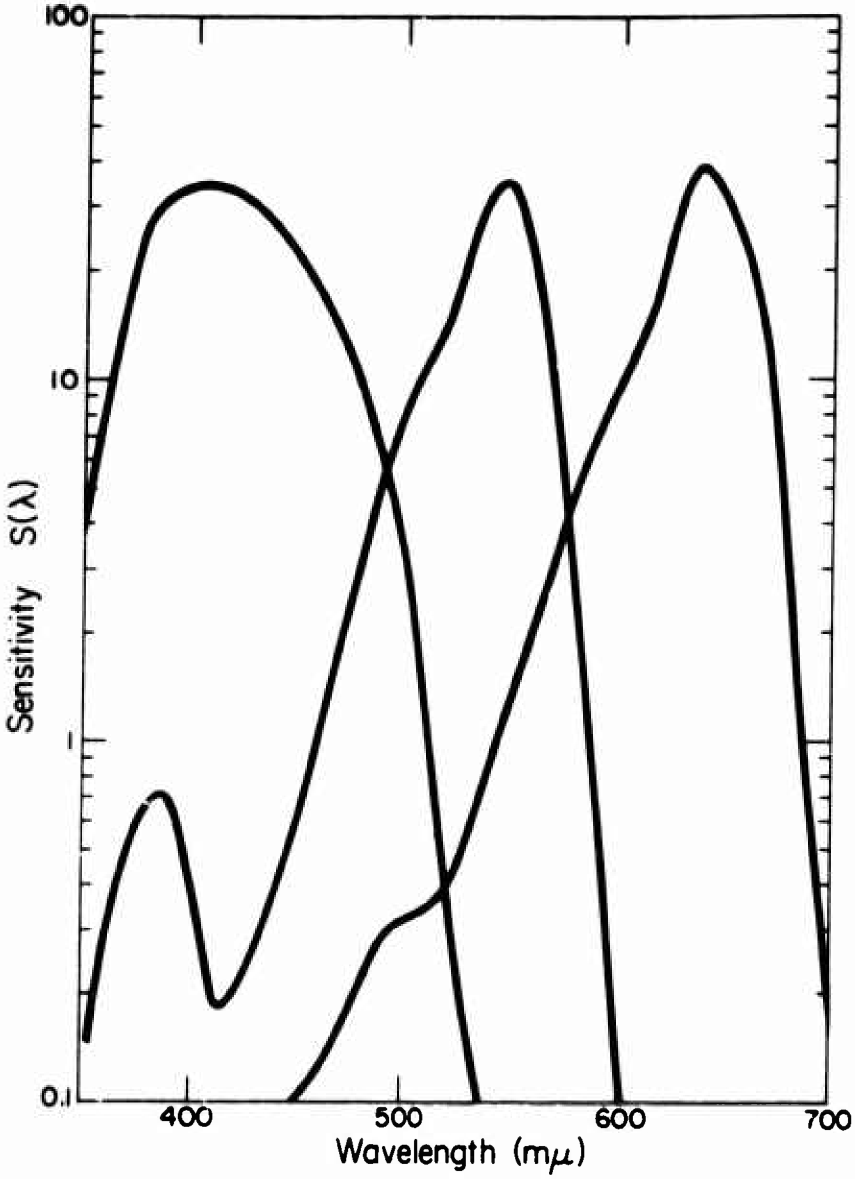


Fig. 1. Spectral sensitivity of Kodak Ektachrome MS Aerographic Film (Estar base) Type SO-151 (2448). ($S(\lambda) = E(\lambda)^{-1}$, where $E(\lambda)$ is the energy in ergs times centimeters^{-2} of monochromatic radiation of wavelength λ required to reduce the dye image density in the individual layer to an equivalent neutral density of 1.0 above minimum density. Data are adjusted to correspond to an effective exposure time of 1/50 second.) (From "Principles of Aerial Color Photograph," A. L. Sorem, Eastman Kodak Company.)

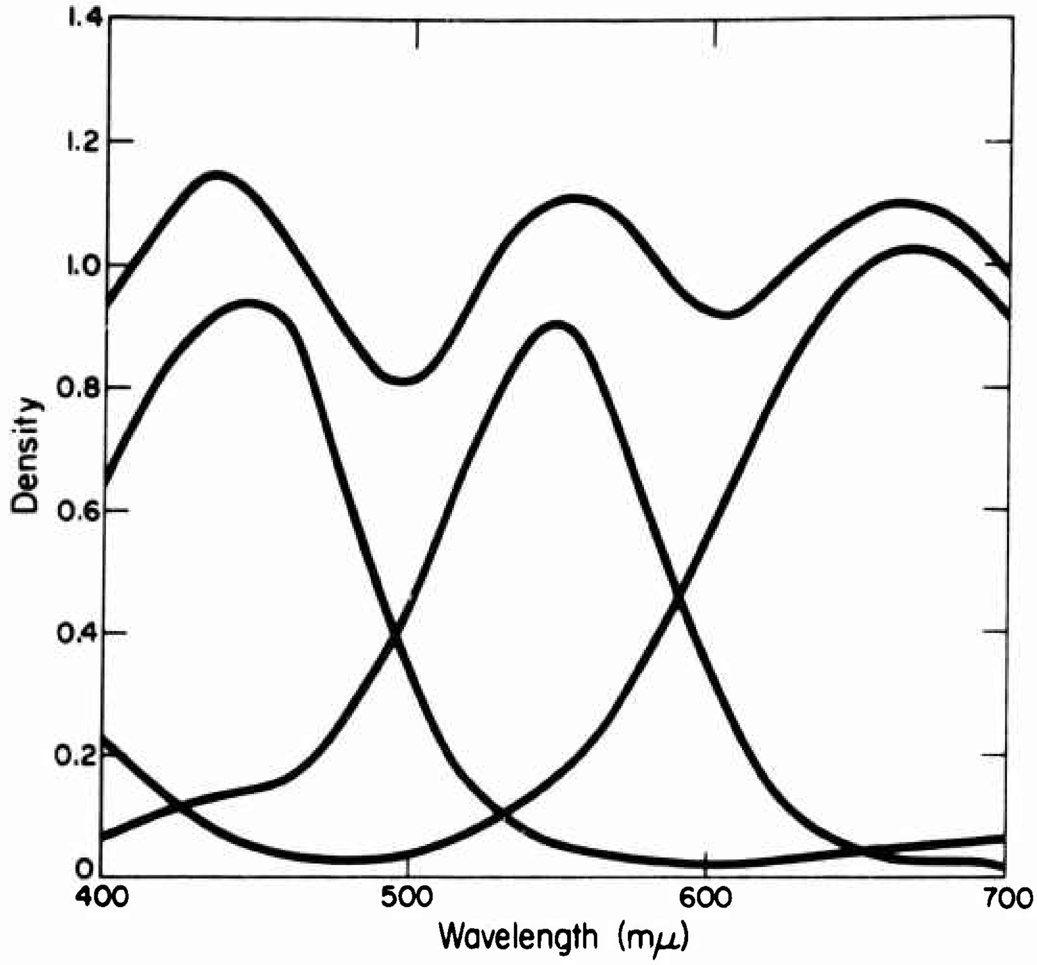
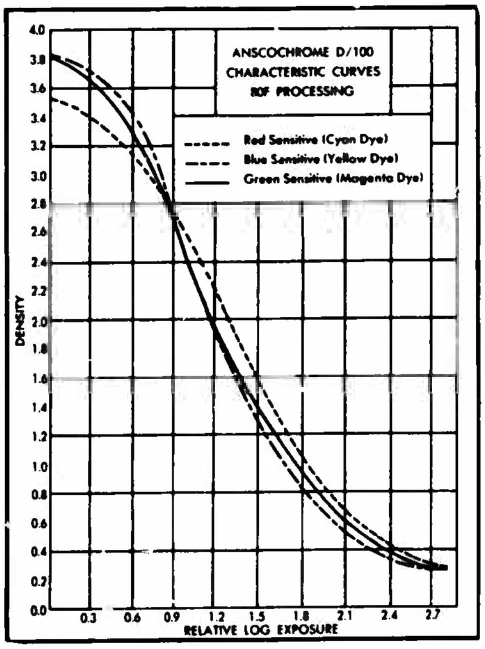


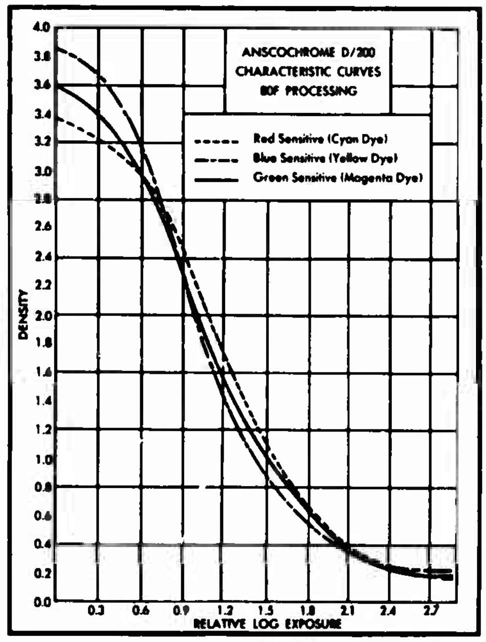
Fig. 2. Spectral densities of Kodak Ektachrome MS Aerographic Film (Estar base) Type SO-151 (2448), normalized to form a unit neutral density. (From "Principles of Aerial Color Photography," A. L. Sorem, Eastman Kodak Company.)

when exposed in aerial cameras. The inherent contrast of the film is well suited for aerial photography. Separate details not recorded or like tones not separated on panchromatic films are distinguished as different colored objects, or by tonal differences (Figs. 3(a) and 4(a)) (4).

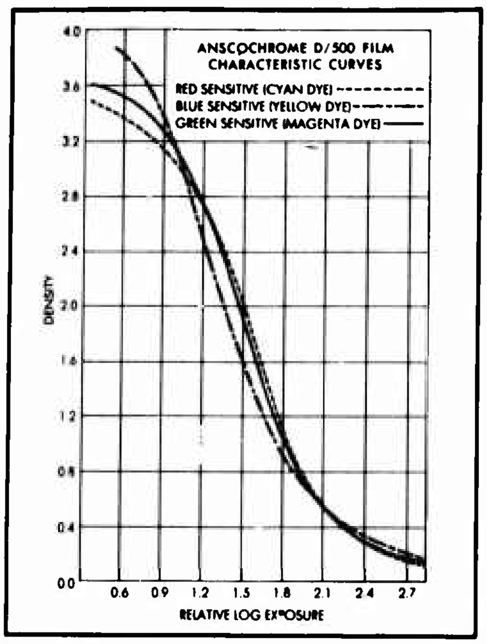
(2) Anscochrome D/200 Aerial Film is a high-speed color reversal film similar in all aspects to D/100 except that its greater sensitivity makes D/200 best suited for low-intensity light



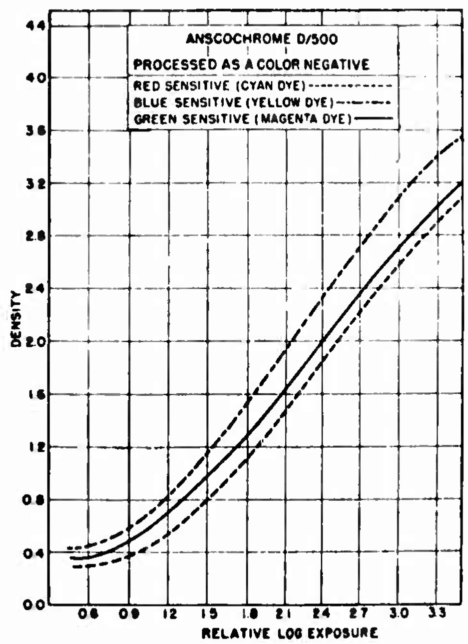
(a)



(b)

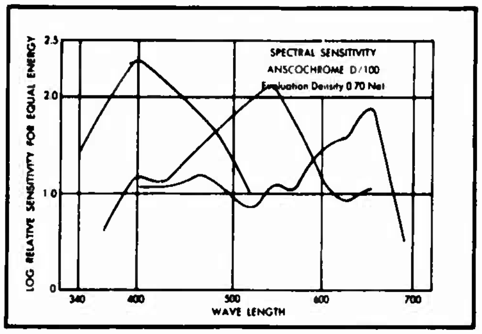


(c)

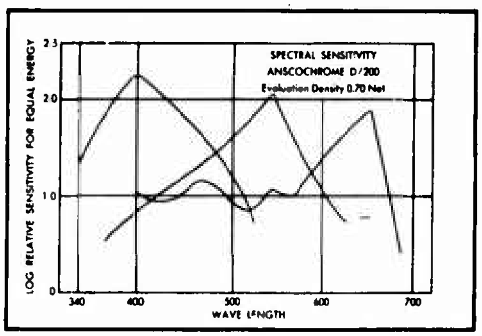


(d)

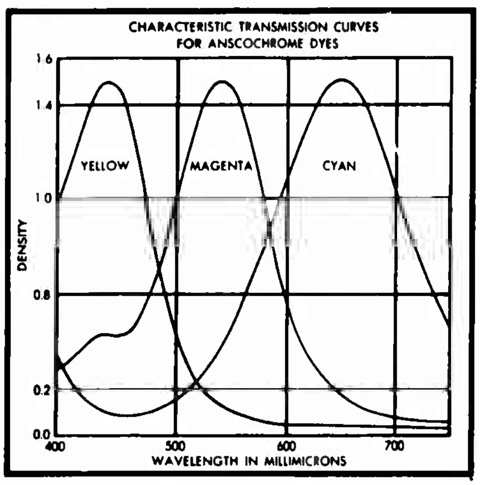
Fig. 3. Characteristic curves of Anscochrome Film (a) D/100, (b) D/200, (c) D/500, and (d) D/500 processed as a negative. (Courtesy of General Aniline and Film Corporation.)



(a)



(b)



(c)

Fig. 4. Spectral sensitivity of Anscochrome Film (a) D/100 and (b) D/200, and (c) characteristic transmission curves for Anscochrome dyes.
(Courtesy of General Aniline and Film Corporation.)

level photography or for cartographic aerial photography with limited aperture lenses where fast shutter speeds are necessary for high-definition results. (Figs. 3(b), 4(b), and 4(c)) (4).

(3) Anscochrome D/500 is a much higher speed film ($2\frac{1}{2}$ times faster than D/200) which can be processed both as a reversal film and as a negative. When processed as a reversal film, it becomes a positive color transparency; when processed as a negative film, prints must be made in order to obtain a color positive. The decision regarding processing can be made at the laboratory since the exposure is the same for either type of processing. Although D/500 is more grainy because of higher speed, the graininess does not detract from its appearance since it also has a marked edging effect which affords good contrast between the objects photographed and their background.

5. Aerial Cameras for Aerial Color Photography. An essential item in any aerial color photography system is the precision cartographic camera equipped with chromatically corrected lens, which will record the optimum plane of focus for all colors of a recorded scene. Since each color is refracted differently as a function of wavelength, the resulting differential magnification and focus of the spectral light requires highly precise lens design and fabrication to obtain the optimum plane of focus (Fig. 5).

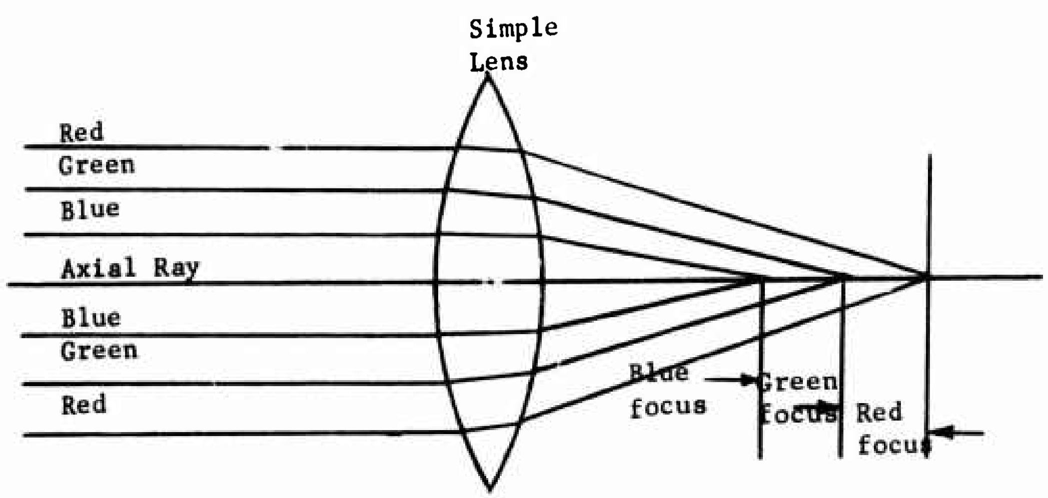


Fig. 5. Differential focusing of the spectrum.

The following precision cartographic cameras are presently available and in use by Government agencies (Table II):

Table II. Mapping Cameras Used for Aerial Color Photography

Camera	Wild Heerbrugg RC-8	Fairchild KC-4	Zeiss RMK A 15/23
Lens	Aviogon 6 In. f/5.6	Geocon I 6 In. f/5.6	Pleogon 6 In. f/5.6
Filters	Clear Antivignetting	Clear Antivignetting	Clear Antivignetting
Resolution	40 Line/Mm AWAR (5401 Agfa)	37.6 Lines/Mm (EK Plus-X)	35 Lines/Mm (Pan 30)
Distortion	Max 10 Microns	Max 10 Microns	Max 10 Microns
Format	9 by 9 In.	9 by 9 In.	9 by 9 In.
Angular Field (Sides)	73 Deg 44 Min	73 Deg 44 Min	73 Deg 44 Min
Exposure Time	1/100 to 1/700 Sec	1/10 to 1/400 Sec	1/100 to 1/1000 Sec
Exposure Control	Rotary Between Lens Shutter Three Lamellae	Waterhouse Fixed Stops - Rapid Shutter	Rotating Between Lens Shutters
Data Recording	Fiducial Marks, Cal. F. L., Lens No., Exp. No., Alt., Time, Level Bubble	Fiducial Marks, Cal. F. L., Lens No., Exp. No., Alt., Time, Data Card	Fiducial Marks, Cal. F. L., Lens No., Exp. No., Alt., Time, Data Card, Level Bubble
Film Capacity	230 Ft by $9\frac{1}{2}$ In.	390 Ft by $9\frac{1}{2}$ In.	400 Ft by $9\frac{1}{2}$ In.

a. <u>Wild Heerbrugg RC-8.</u> The Wild Camera (Fig. 6) constructed with the 6-inch focal length Universal-Aviogon lens is employed extensively by the Coast and Geodetic Survey, Environmental Sciences Services Administration, in obtaining aerial color photography. The lens cone produces a format 23 by 23 centimeters (9 by 9 inches), and has an angular field of 90 degrees. The lens has been corrected to the optimum for both visible and film recordable infrared ranges of the spectrum. Therefore, the camera can be used for panchromatic film, infrared film, color film, and infrared color film. The falloff in luminance closely follows the cosine to the third power of the angle of incidence and is completely balanced by color neutral graded density coatings on the filters. It also has distortion of less than ± 0.01 millimeter. The lens cone is equipped with a rotary shutter for continuous regulation of exposure time from 1/100 to 1/700 second with an efficiency of more than 80 percent at relative exposure aperture f/5.6. Resolving power is shown in Table III.

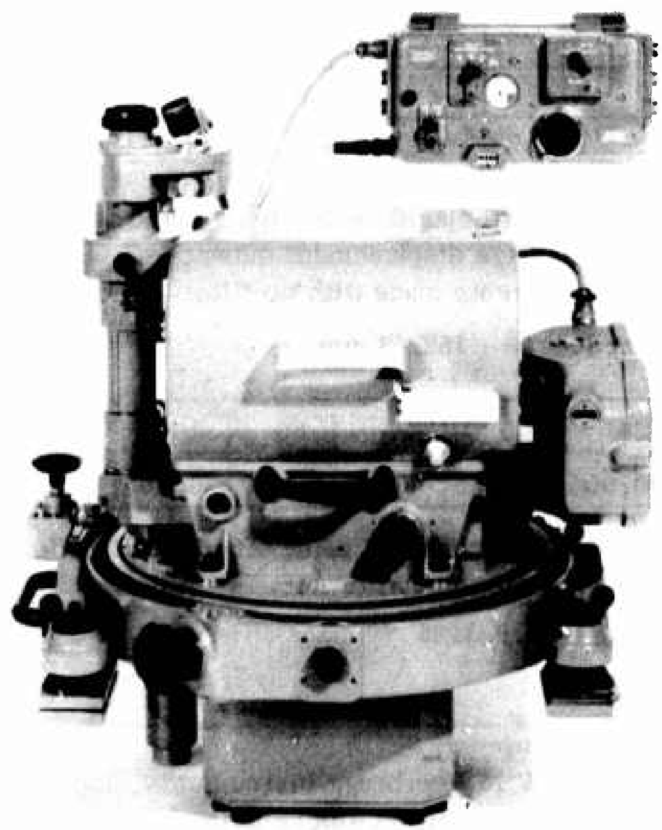


Fig. 6. Wild RC-8 automatic camera.

Table III. Resolving Power of RC-8 Camera

Lens Cone		Lens	Calibration date: 9.9.1965
Type:	RC5/RC8	Type:	Universal - Aviogon
No.:	15 UAg 286	No.:	286
Size:	9" x 9"	f =	153 mm
		max. aperture:	f:5,6

Resolving Power (Lines per millimeter)

High contrast and max. aperture f:5,6

Film: Agfa Isopan IFF 13 Planfilm
Glass plate:

	0^o	5^o	10^o	15^o	20^o	25^o	30^o	35^o	40^o	45^o	50^o	55^o	60^o
rad.	53	53	52	51	49	38	46	44	29	9			
tang.	53	53	51	49	52	49	44	40	35	17			

rad.													
tang.													

Distortion in millimeters

The given distortion is the arithmetic mean of the four half-diagonals. Positive values denote image displacement outwards.
Goniometer measurements made with no filter on lens cone.

Calibrated focal length: 152.83 mm

Radius	20	40	60	80	100	120	140	148
Distortion	+0,004	+0,005	+0,003	0,000	-0,005	-0,005	+0,002	+0,011

The displacement of the principal point of autocollimation from the intersection of the diagonals (fiducial center) is within 0,02 mm

Date of Dispatch: 22.9.1965

WILD HEERBRUGG
Limited

Used by permission Wild Heerbrugg Instruments, Inc., from Table #2 of the Calibration Certificate for RC8 Camera with Universal Aviogon Lens #286.

b. Fairchild KC-4. The Fairchild Camera and Instrument Corporation KC-4 Camera (Fig. 7) is fabricated with a Perkin-Elmer 6-inch focal length Geocon I lens with Waterhouse stops of f/8, f/11, f/16, and f/22. Shutter speeds are 1/10, 1/25, 1/50, 1/200, and 1/400 second. The lens cone, with a 9- by 9-inch format, has an angular field of 90 degrees and is fully color corrected for the visible and infrared spectrum. Therefore, the KC-4 can also be used for panchromatic, infrared, color, and infrared color film. The distortion is less than 0.01 millimeter with a probable error of 0.0005 millimeter. The resolving power is shown in Table IV.

c. Zeiss RMK A 15/23 Wide-Angle Survey Camera. The Zeiss Aerotopograph Company in Munich, West Germany, manufactures the RMK A 15/23 Wide-Angle Survey Camera (Fig. 8), which is a 6-inch focal length camera with a Zeiss Pleogon lens. Its angular field is 93 degrees with shutter stops of f/5.6, f/8.1, and f/11. The Zeiss Aerotop shutter is a between-the-lens type with continuously rotating discs, which permit shutter speeds to be varied from 1/100 to 1/1000 of a second. The chromatic corrections in the lens allows for the range of panchromatic emulsions from 650 to 850 millimicrons. Therefore, the RMK A 15/23 camera can be used with panchromatic, color, infrared, and infrared color film.

Some reconnaissance cameras recommended by the manufacturers as having color capability are listed in Table V. The effects of most reconnaissance lens systems optimized for resolution are not sufficiently known or calibrated in regard to color.

6. Processing Equipment for Aerial Color Photography. A major obstacle to previous wider employment of aerial color photography has been the lack of reliable rapid film processors for $9\frac{1}{2}$-inch-wide aerial color photography. The requirement for quality control in processing is stringent because the color balance in color photography has less tolerance for variations in photographic chemistry and temperature than conventional black and white aerial photography.

a. Processing Aerial Color Photography. Mapping or reconnaissance systems which employ aerial photography use roll film because of the large number of photographs exposed. Quality control methods under which color emulsions are manufactured limit the length of film to 125 feet, although the format may be as wide as $9\frac{1}{2}$ inches; therefore, tank processing is required. The principal difference between processing black and white film and color film is that more rigid control must be exercised over

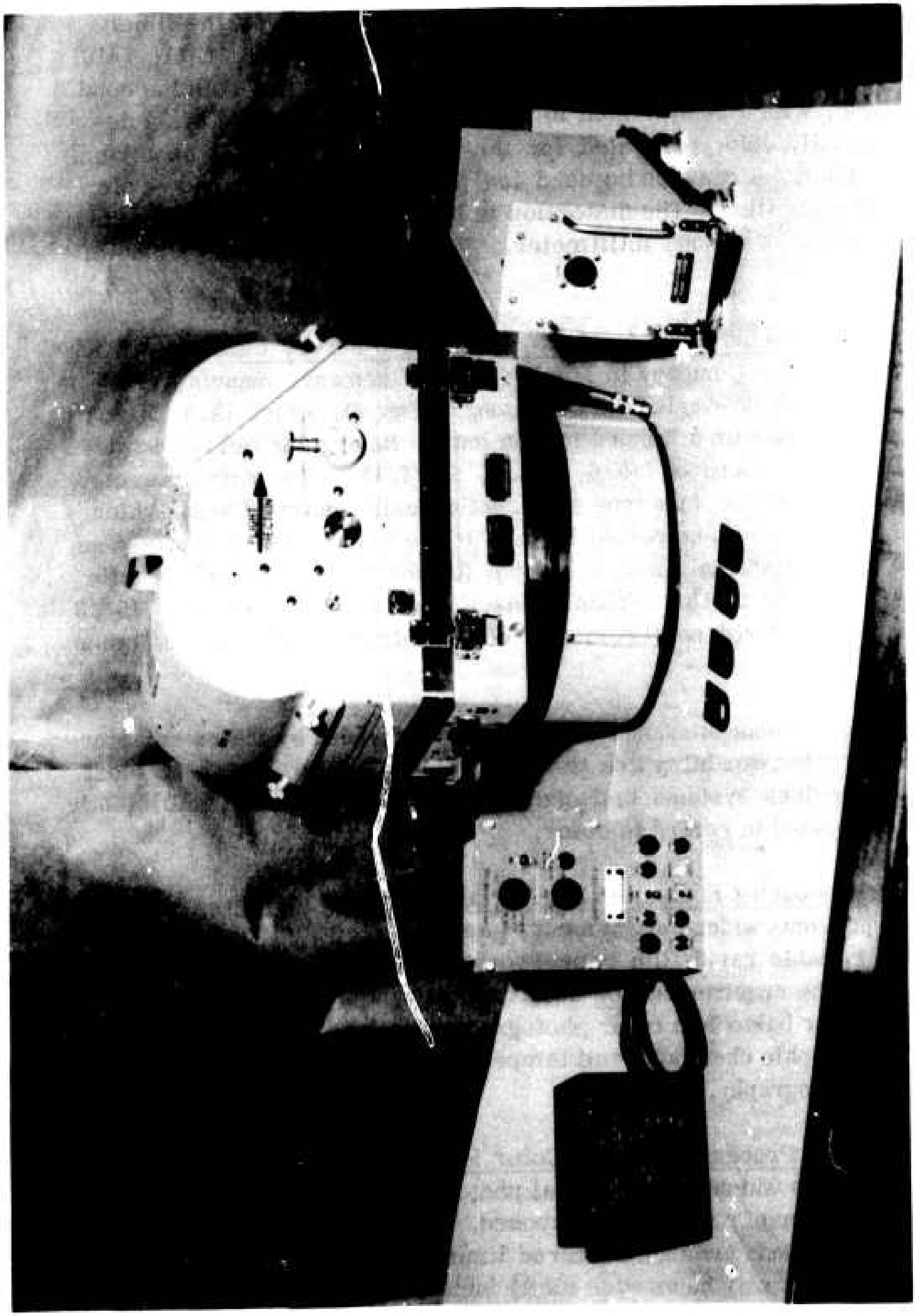


Fig. 7. Fairchild KC-4 camera.

Table IV. Resolving Power of KC-4 Camera

Lens No. 799648

Camera No. 65-1001
Date 2/10/66

I. FOCAL LENGTH

Flange Focal Distance	Equivalent Focal Length	Calibrated Focal Length
MM	MM	MM
99.771	152.085	152.081

The probable errors of these determinations of focal length do not exceed 0.025 mm.

II. DISTORTION

Distortion Referred to the Calibrated Focal Length

7.5°	15°	22.5°	27.5°	30°	32.5°	35°	37.5°	40°	42.5°	45°
0.000	+0.002	+0.006	+0.008	-0.009	+0.008	-0.004	-0.002	-0.005	-0.010	-0.014

The values of the distortion are measured in millimeters and indicate the displacement of the image from its distortion-free position. A positive value indicates a displacement from the center of the plate. The probable error is approximately 0.005 mm.

Tangential Distortion

The Tangential distortion is 0.010 mm.

III. AVERAGE RESOLVING POWER

Emulsion: 5401 AWAR 37.8

	0°	7.5°	15°	22.5°	27.5°	30°	32.5°	35°	37.5°	40°	42.5°	45°
Tangential	57	54	53	44	39	41	39	34	31	23	29	26
Radial	64	53	56	48	39	37	34	32	29	32	29	31

The values of the resolving power are given at specified intervals from the center of the field and are obtained by photographing suitable test charts comprised of patterns of parallel lines. The series of patterns of the test chart are imaged on the negative with lines per millimeter spaced from 4 to 129 in $\sqrt[6]{2}$ intervals.

The row marked "Tangential" gives the number of lines per millimeter in the image on the negative of the finest pattern of the test chart that is distinctly resolved into separate lines when the lines lie perpendicular to the radius drawn from the center of the field. The row marked "Radial" gives similar values for the pattern of test lines lying parallel to the radius.

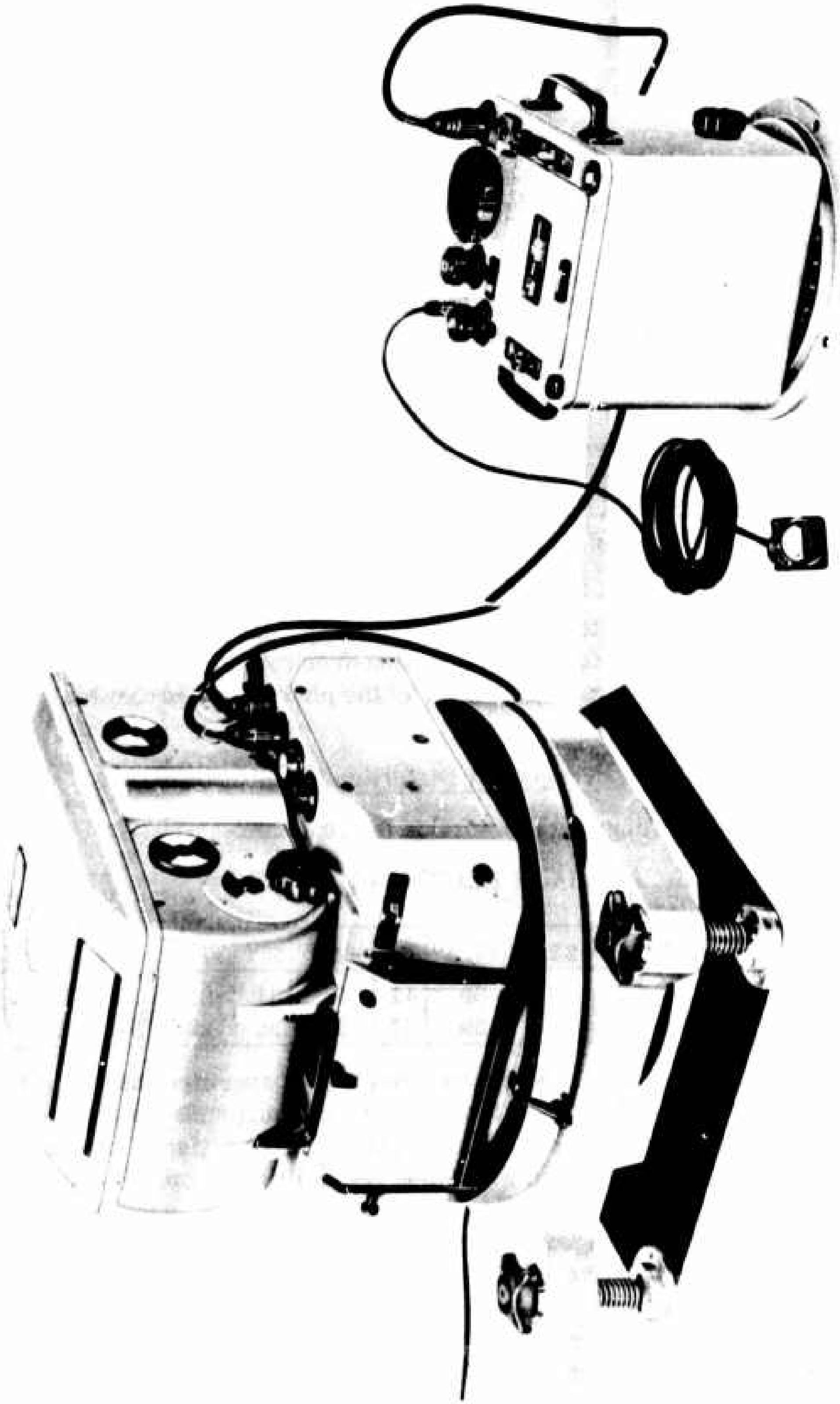


Fig. 8. Zeiss RMK A 15/23 camera.

Table V. Reconnaissance Cameras Used for Aerial Color Photography

Camera	KA-50	KA-55A	KA-56	KA-60
Type	Frame	Panoramic	Panoramic	Panoramic
Lens	F. L. 1-3/4 In. f/5.6	F. L. 12 In. f/5.6	F. L. 3 In. f/4.5	F. L. 3 In. f/2.8
Resolution	40 Lines/Mm AWAR Plus-X	75 Lines/Mm AWAR Plus-X	34 Lines/Mm LWAR[a] Plus-X	45 Lines/Mm LWAR[a] Plus-X
Format	4.5 by 4.5 In.	4.5 by 18.9 In.	4.5 by 9.25 In.	2.25 by 10.00 In.
Angular Field	104 Deg 20 Min	90 Deg Lateral 21 Deg 14 Min Fore and Aft	180 Deg Lateral 74 Deg Fore and Aft	180 Deg Lateral 40 Deg Fore and Aft
Exposure Time	1/60 to 1/3000 Sec	1/100 to 1/3000 Sec	1/90 to 1/5000 Sec	1/100 to 1/10,000 Sec
Exposure Control	Focal plane shutter - AEC[b]	Scanner Slit	AEC[b] Rotary Prism	AEC[b] Rotary Prism
Data Recording	CRT Recording	Binary ADAS. Frame Counter, Fixed Data Recorder, Cycle Counter, Elapsed Time Meter	Frame Counter, CRT Recording	Vrame Counter, Data Annotation
Film Capacity	250 Ft by 5 In.	1000 Ft by 5 In.	250 Ft by 70 Mm	500 Ft by 5 In.

(a) Linear weighted average resolution.
(b) Automatic exposure control.

chemistry, water purity, and temperature when processing color film. Processing black and white photography requires few changes of chemicals, principally: developing, washing, fixing, and washing. However, color photography requires a minimum of 14 changes of chemicals in processing to a transparency and 9 changes in processing to a negative.

(1) Wind-Rewind Process. The simplest processing procedure involves the use of small portable tanks, approximately 12 inches high by 16-3/4 inches long by 9 inches wide. The entire roll is treated as a unit in each bath in succession. Two reels are mounted on a frame. During processing, the film is rewound from one reel to the other by a drive motor, while the assembly is immersed in the processing bath. At the periodic conclusion of each process, the entire assembly is removed and placed in another tank for washing, then removed and placed in another tank of chemical for the next step. This method termed the wind-rewind process (5) is presently in use at the Coast and Geodetic Survey (Fig. 9). Initial equipment cost is low and the system can be rapidly adapted to processing black and white photography by changing the chemical baths.

(2) Versamat Film Processor. The Versamat produced by the Eastman Kodak Company for automatic processing of black and white $9\frac{1}{2}$-inch-wide aerial roll film has been modified to accommodate color photography. It is a continuous processor, which transports the film by a series of rollers, which are self-threading. Rollers serve to agitate the solutions as the film passes through the several tanks of chemicals. The Versamat is presently being used and undergoing tests at several installations, including the U. S. Air Force, the U. S. Navy, and National Aeronautics and Space Administration (Fig. 10).

b. Color Printers.

(1) The majority of color printers in use operate by projection printing. If color transparencies are supplied, they are projected onto an internegative, which is then processed and reprojected onto color prints or color transparencies for duplication. During reprojection, color filters are employed to achieve a visual color balance, which represents the operator's color sense. Previously, the U. S. Navy used this procedure. In recent months, the Rainbow printer (Fig. 11) developed by Eastman Kodak provides a means of contact color printing by using three individually spectrally pure light sources for printing color. Goodyear Aerospace Corporation is

Fig. 9. Wind-rewind method of processing color film.

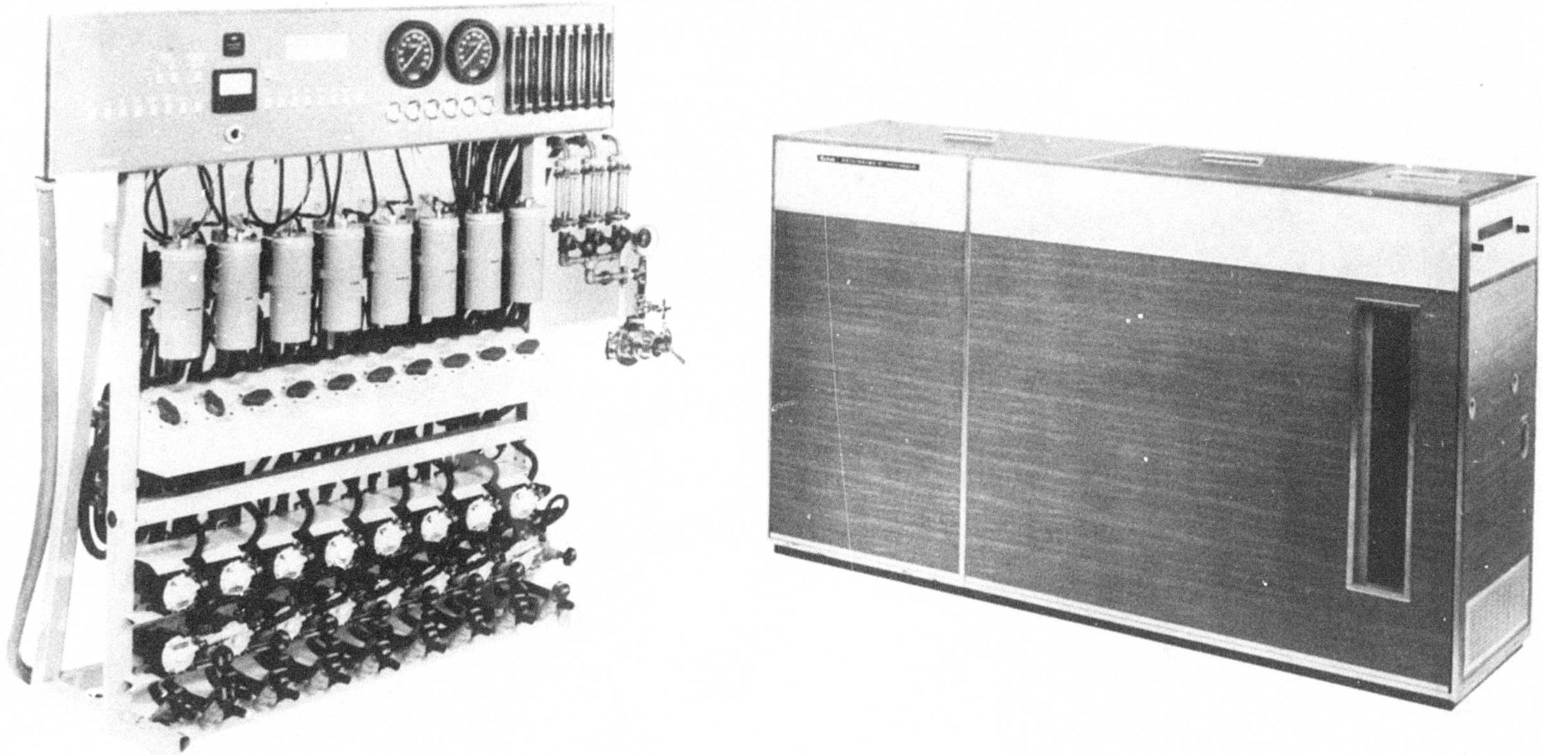


Fig. 10. Model 1411-M Versamat processor. (Courtesy of Eastman Kodak Company.)

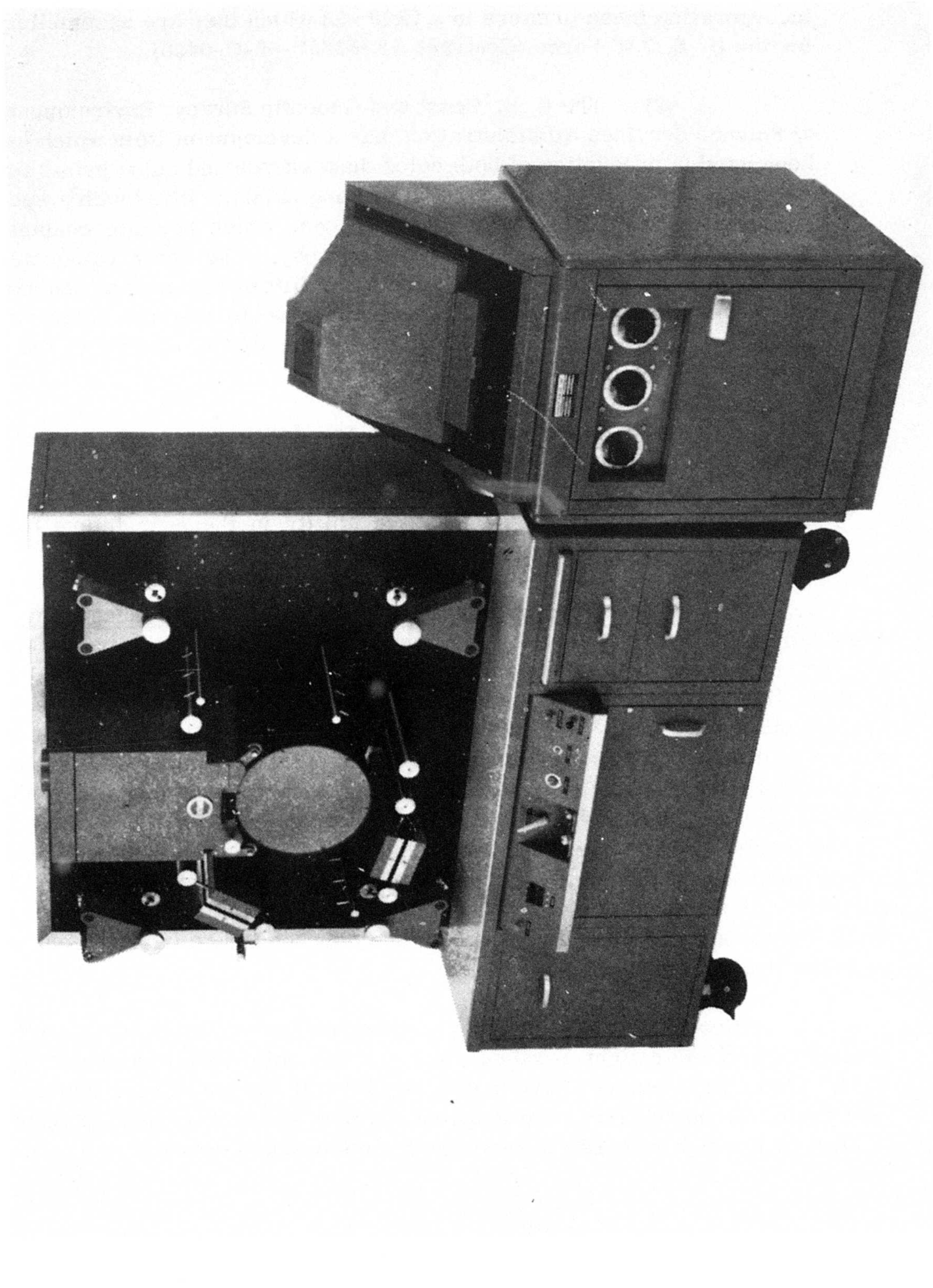


Fig. 11. Rainbow continuous printer and control unit.

incorporating these printers in a field van which they are assembling for the U. S. Air Force (Contract AF-33657-67-C-0450).

(2) The U. S. Coast and Geodetic Survey, Environmental Science Services Administration, has a development item which has been used in production of both color diapositives and color prints for several years. It is an electronic dodging printer, fitted with a specially designed color corrected light source, which permits contact printing of $9\frac{1}{2}$-inch-width aerial photography. The color values are read with a color densitometer, and color filters are used to achieve color balance. Sensitometric strips are used to test the color response of the color emulsion and detect accidental fogging of the emulsion.

(3) Other organizations are developing color printers as the state-of-the-art is advancing; Fairchild-Hiller, the Itek Corporation, and General Aniline and Film Corporation have items under development, which will increase capability in the near future for controlled color printing and processing.

7. Viewing and Plotting Equipment for Aerial Color Photography. Light tables which are equipped with fluorescent light sources are satisfactory for viewing aerial color photography because of the highly actinic value of their light. Stereoplotting equipment for use with color photographs present other problems, particularly if they are dichromatic. Red and cyan filters on Kelsh plotters or Multiplex plotters make it impossible to use color unless the images are diapositive separated without the use of the colored filters. One answer to this problem was given by the U. S. Geological Survey's Stereoimage Alternator, an image separation system which can be applied to dichromatic projection plotters. The system consists of rotating cylindrical shutters in both the projection field and the viewing field, synchronized so that each eye can see only the image from the corresponding projector (Fig. 12).

Binocular-type plotters are effective for viewing aerial color photographs if their light sources approach the color temperature of daylight. Some light sources have been modified with the addition of fluorescent grids. In other cases, the tungsten filament lamps have been designed to burn with a high intensity to increase the color temperature.

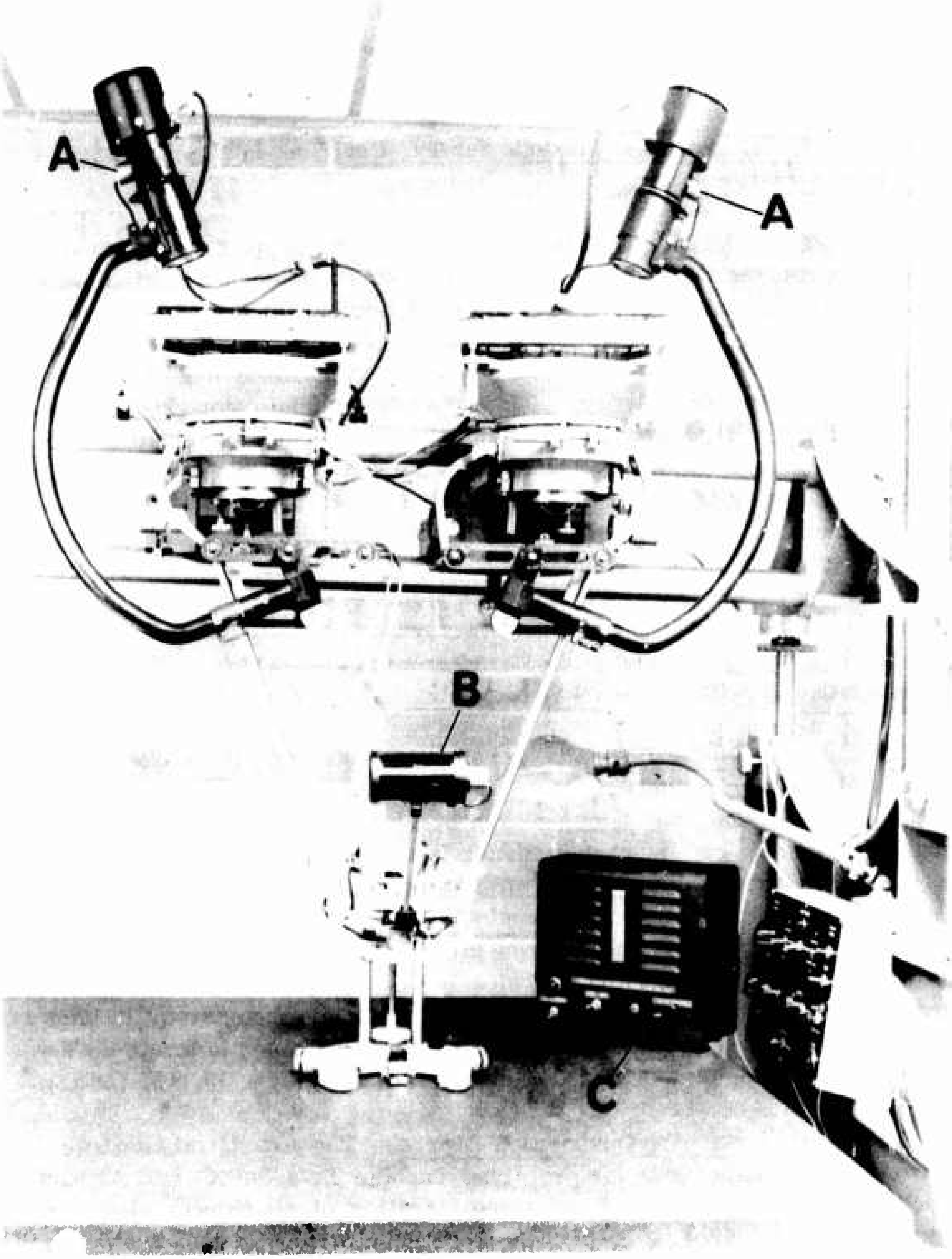


Fig. 12. Stereoimage Alternator system installed on Kelsh K-100 plotter. A. Projection shutter motors. B. Viewing shutter assembly. C. Control logic unit. (Courtesy of U. S. Geological Survey.)

III. APPLICATION OF AERIAL COLOR PHOTOGRAPHY TO SPECIFIC REQUIREMENTS

8. U. S. Coast and Geodetic Survey, Environmental Science Services Administration, Department of Commerce.

a. Mapping Coast Lines. For hydrographic control and coastal charts, the Coast Survey requires accurate and highly detailed maps of shoreline and alongshore features. Aerial photography is taken in color, infrared, and black and white at different tidal periods. When exposed at near high water, the infrared photographs define the mean high-water line; which is shoreline for charting. Tide controlled aerial color photography is taken at mean low water and is the best known means of delineating foreshore and offshore features. The color of the water in a single photograph changes gradually from the clay soil near a river mouth to green in clear inshore areas, then to blue-green, to blue and blue-violet as greater depths are photographed (Figs. 13 and 14). The cameras used are 6-inch focal length with a 9- by 9-inch format, which yields even illumination over the entire focal plane without need for a heavy neutral density filter to compensate for loss of illumination at the corners of the photograph. The maximum relative aperture is usually f/5.6 (6).

b. Navigation Aids. Another of the principal uses of aerial color photography in the Coast and Geodetic Survey is to locate channel lights, day beacons, and buoys moved by storms and collisions so that charted positions can be corrected. It is usually possible to identify and locate the navigational aid in the office without a trip to the field. There are approximately 40,000 navigational aids, most of them in bays, harbors, and intracoastal waterways, a large proportion of which are subject to change. Bottom features are also clearly visible when compared to prior hydrography with an accuracy of $\pm$ 5 percent. Color photography is often used to detect a channel which has changed its position and to locate the new position even though the depths may be approximate (Figs. 15, 16, and 18).

c. Airport Obstruction Charts. The Coast and Geodetic Survey is also responsible for preparing Turbine Data Sheet and Airport Obstruction Charts, which require the elevation of all objects along the takeoff flight path above a $2\frac{1}{2}$-percent slope from the end of each runway at all airports used by commercial airliners. The objects must be located and positioned for 20 miles from the end of each runway. Many of the obstacles are trees, perhaps a single highest tree in a grove of trees, which is often difficult to locate from the ground. With stereoscopic color photography coverage, the crowns of the trees can be more easily located than

Fig. 13. Key West, Florida.

(U. S. Coast and Geodetic Survey aerial photograph.)

Fig. 14. Hyannis Port, Massachusetts.

(U. S. Coast and Geodetic Survey aerial photograph.)

Fig. 15. Cape Charles, Virginia.

(U. S. Coast and Geodetic Survey aerial photograph.)

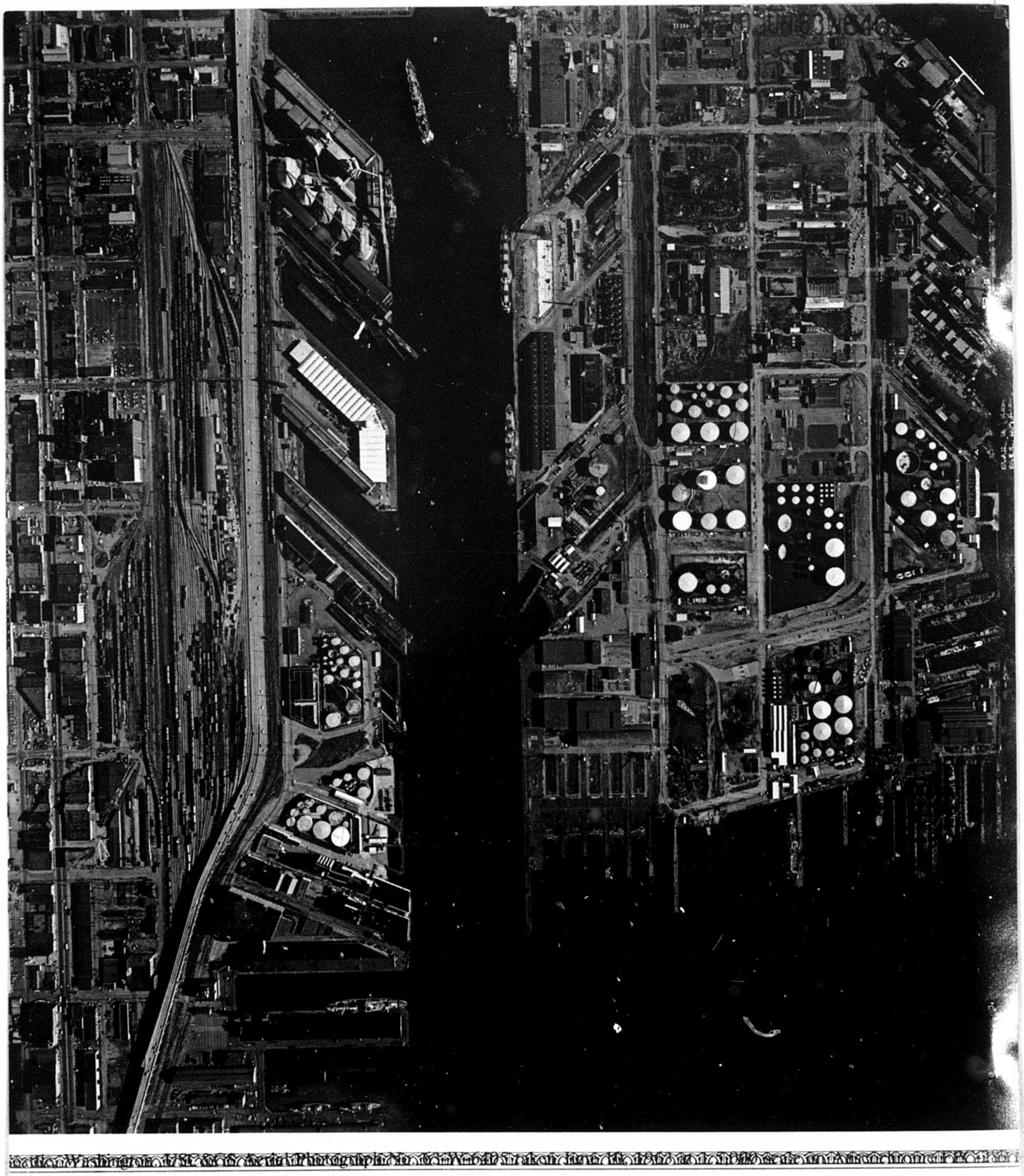


Fig. 16. Seattle, Washington.

(U. S. Coast and Geodetic Survey aerial photograph.)

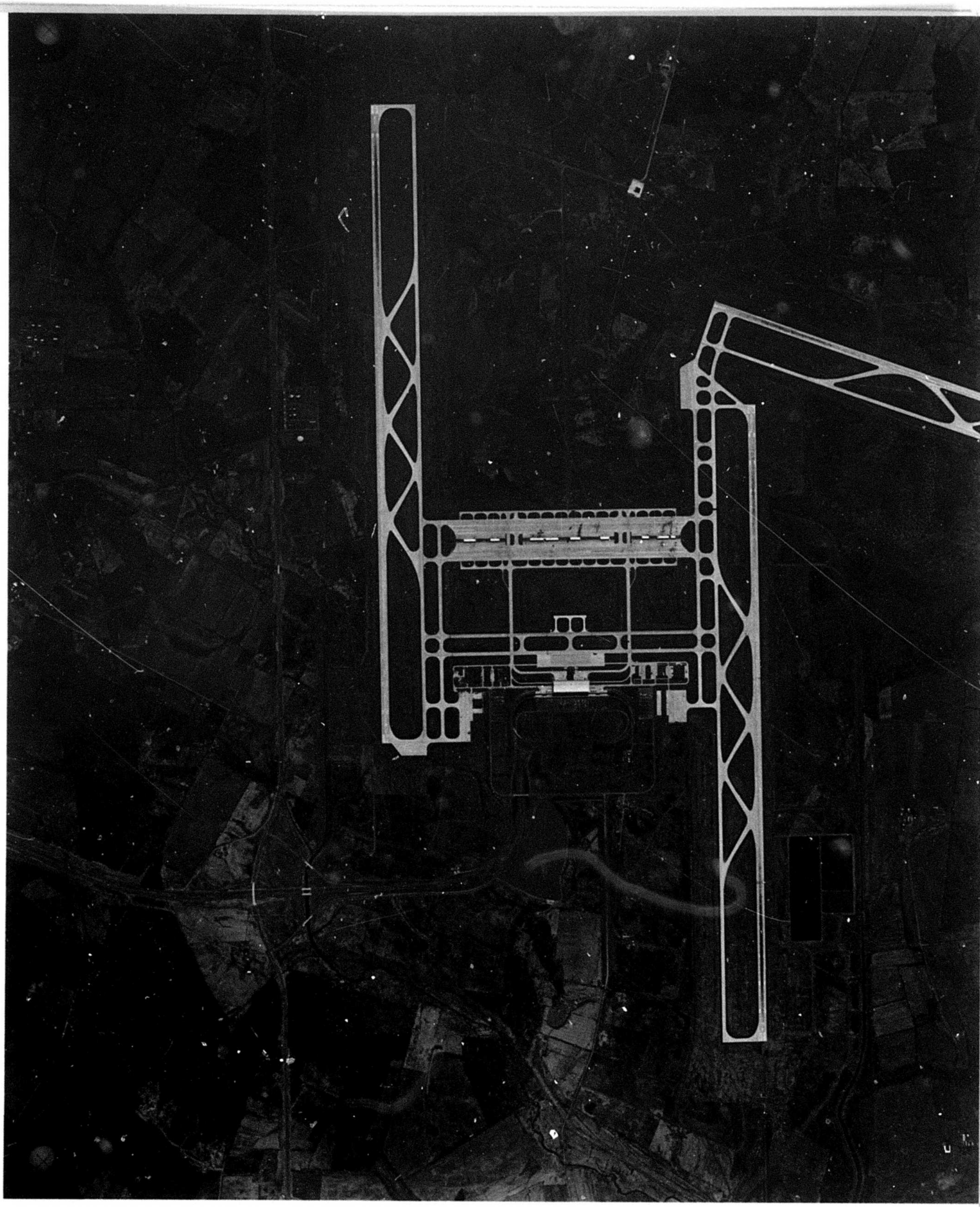


Fig. 17. Dulles Airport, Virginia.

(U. S. Coast and Geodetic Survey aerial photograph.)

Fig. 18. Baltimore Harbor, Maryland.

(U. S. Coast and Geodetic Survey aerial photograph.)

on panchromatic black and white photography, thus the obstruction charts can be prepared more rapidly (Fig. 17).

d. Special U. S. Coast and Geodetic Survey Equipment. In order to control processing chemistry of color film, the Coast Survey has developed a method of marking blank spaces in the aerial film (Fig. 19) for later exposure of color step wedges by means of a sensitometer. When processed, the step wedge will indicate the condition of the film and the quality of the processing as well as incidental fogging during flight operations. The step wedge will indicate exposure errors, processing errors because of chemistry imbalance, color shifts inherent in film emulsions, and also densities resulting from the wind-rewind method in the middle and ends of the strip (Fig. 20).

The illumination system of the Wild B-8 plotter used by the Coast Survey was modified by the use of cool, gaslight tubes arranged in a grid pattern. The lights have a rheostat control and do not require a cooling system (6).

9. U. S. Geological Survey, Geological Division, Department of the Interior.

a. Geological Exploration. The first field evaluation study of aerial color photography by the U. S. Geological Survey was made in 1955 of the Furnace Creek Area, Death Valley, California (7). The second evaluation was made of areas near Tonopah and Goldfield, Nevada, in October 1958. The color photographs of the three test areas were made at 10,000-foot flying height with a K-17 aerial camera equipped with a 12-inch focal length lens. Six flight strips parallel to the topographic and geologic grain of the Furnace Creek Area were exposed. Preliminary evaluation indicated the following:

(1) Photograph color sequences could be correlated with ground color sequences, which characterize undisturbed areas.

(2) The absence of a specific color in an established photograph and ground color sequence suggests a stratigraphic or structural complexity. This was used to detect a low-angle fault in the Funeral Mountains.

(3) Offsets or interruptions of established color sequences suggest high-angle faulting.

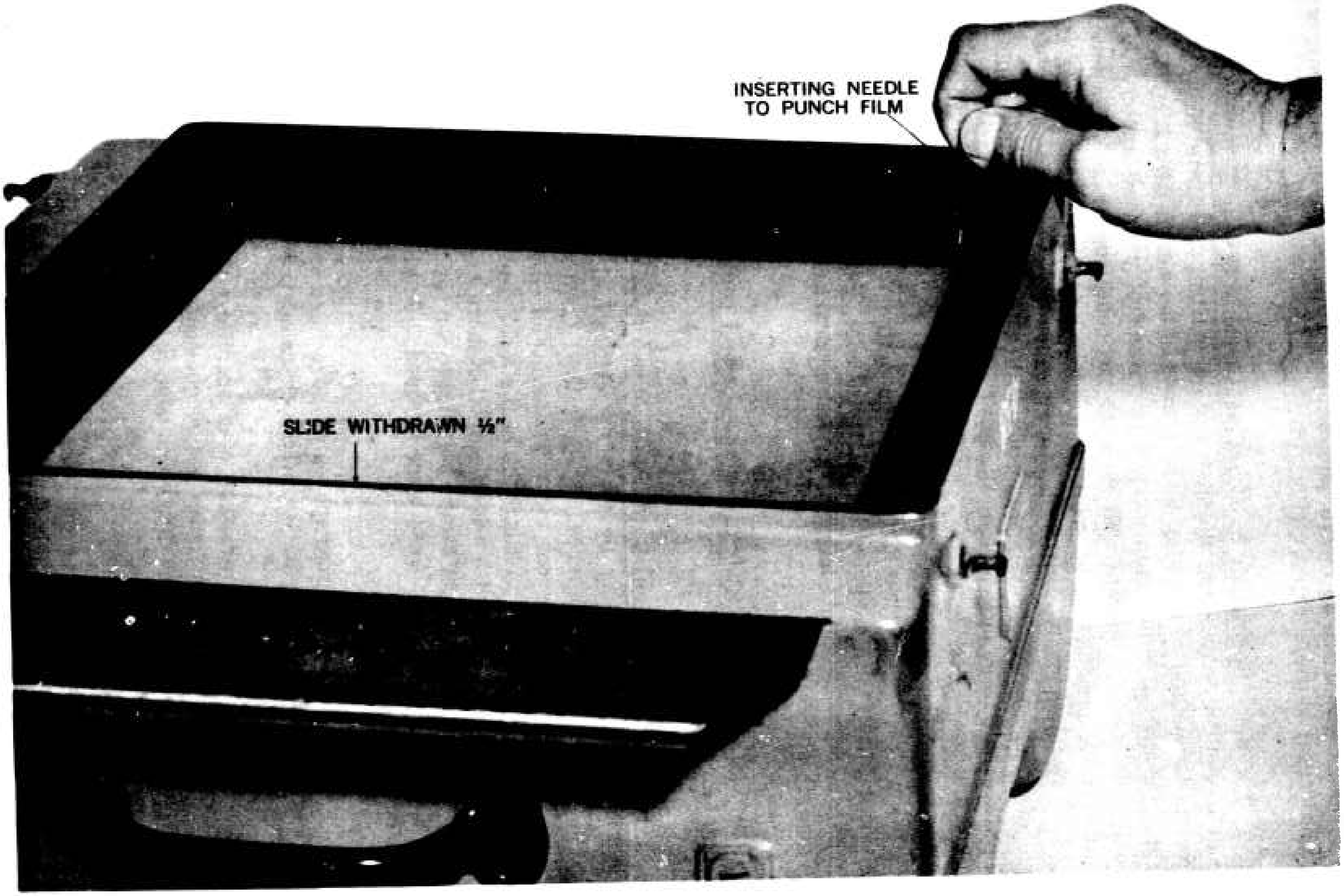


Fig. 19. Wild RC-8 magazine - marking film with needle.

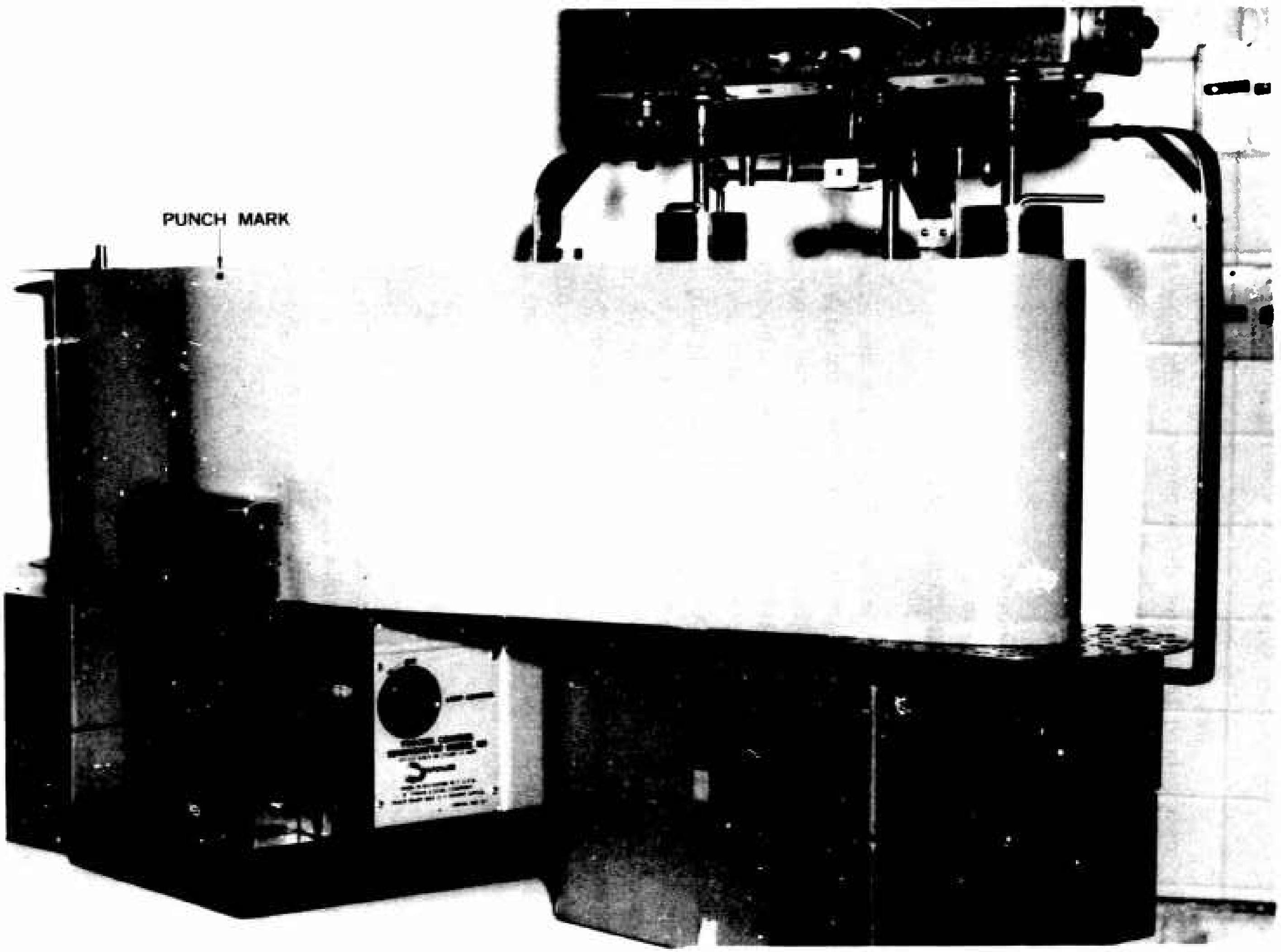


Fig. 20. Marked aerial film.

(4) Formation and stratigraphic units show that a characteristic overall color can be identified and mapped with respect to flight altitude and appropriate viewing distance.

(5) Strata different in age but similar in rock type can be recognized by color differences. Photograph color fidelity with respect to ground color is difficult to evaluate, but fidelity is not considered to be essential for geologic uses provided that color discriminations are recorded.

(6) Concentration of ground color in the yellow range causes dense areas on the color film, but concentration of ground color in the red range causes thin areas on the same film.

The impression of color on the film is related to edge gradients of images and viewing distances; the loss of image sharpness and increase in lightness values take place at the expense of color chroma (pale or vivid) as viewing distances increase. Atmospheric haze, not distance, is considered the primary cause of these losses. The haze is not usually appreciable in mountain areas or in the upland parts of the test area; distinct impression of color can be obtained and recorded from viewing distances up to 11 miles. Haze is usually present in lowland areas, and color differences could not be detected from distances of 2 miles. Different sun angles and light intensity because of time difference during the day affected the impression of color hue. Representative samples of geological photography are shown in Figs. 21, 22, and 23.

In the Goldfield and Tonopah test areas, correlations were first established (8) between lithologic units and their color and landform as shown on aerial color photographs. Margins of outcrop areas characterized on the photographs by similar color and landform were visited in the field to determine their relationships to geologic contacts previously mapped.

Preliminary results indicated that most of the lithologic units previously mapped can be recognized by color or groups of color visible on the aerial color photographs.

In general, photograph colors correspond well with ground colors; however, all of the aerial color photographs had a faint yellowish overtone causing the photograph colors to shift toward the yellowish part of the spectrum; this did not have a significant effect upon the color correlation. The 10,000-foot photography of other test areas had yellowish

Fig. 21. Colorado River, Arizona. (U. S. Air Force photograph.)

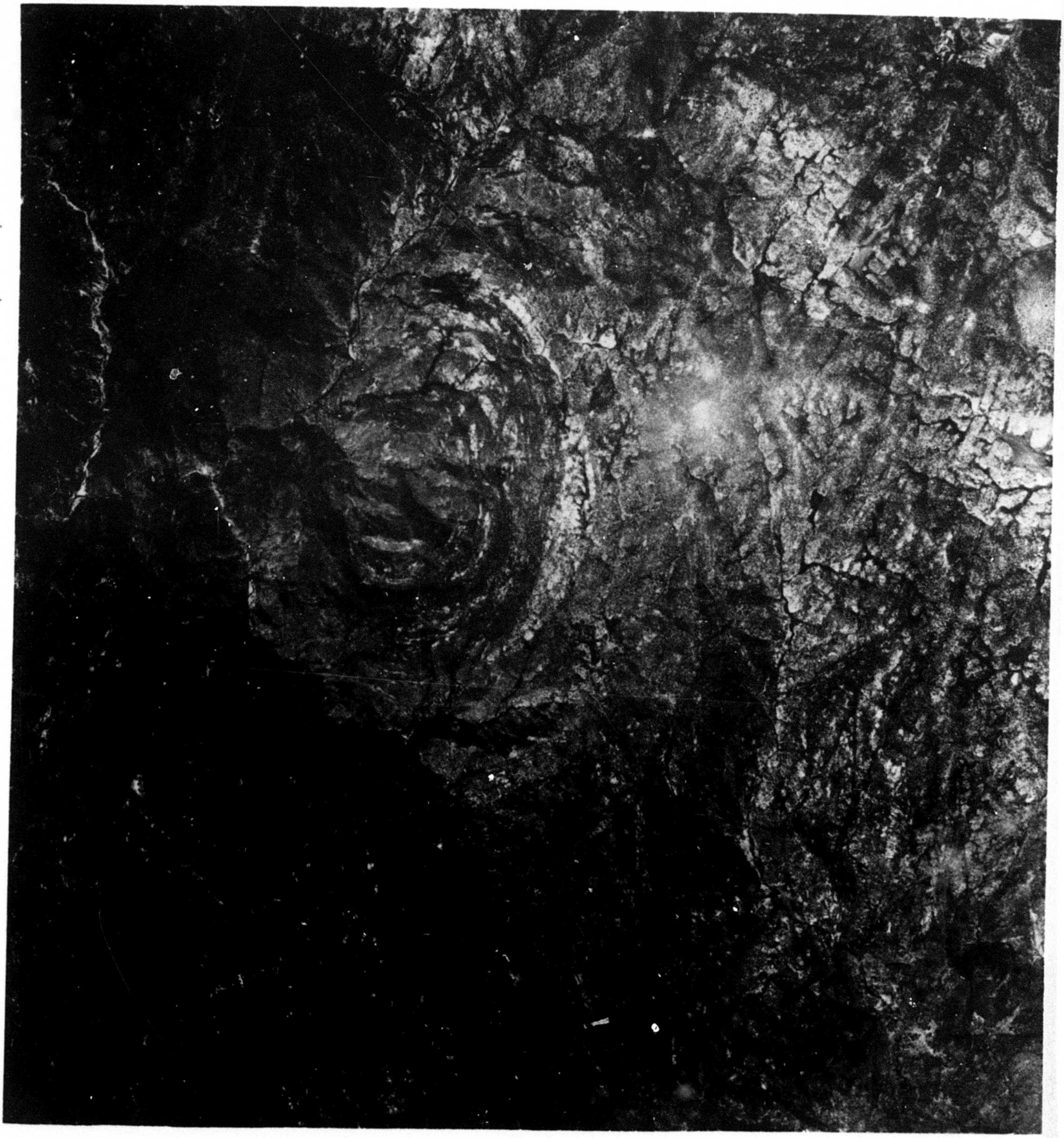


Fig. 22. Geological formation near Sierra Nevada Mountains, California. (U. S. Air Force photograph.)

Fig. 23. Snowcapped crests of Sierra Nevada Mountains, California. (U. S. Air Force photograph.)

overtones, whereas 20,000-foot photography had bluish overtones; this was related in part to the differences in daylight illumination characteristics at the altitude at which the film was exposed.

In 1960, Minard (9) reported that interpretation of aerial color photographs in the Piedmont Coastal Plain Area facilitated the mapping of two formational contacts, which were extremely difficult to locate other than by extensive augering.

Further work by Fischer in 1962 (8) indicated that aerial color photography was helpful in New Mexico in mapping the distribution of residual soils, in recognizing relic sinkholes, and in determining the origin of drifting sand onto a limestone capped mesa.

b. Water Resources. The Water Resources Division of the U. S. Geological Survey is responsible for locating and recording the water resources of the United States. Accurate measurements of drainage networks are necessary for studies in hydrology. Topographic maps must show accurate classification as well as consistent patterns of stream networks. In 1963, the Coast and Geodetic Survey began obtaining aerial color photography for use by the U. S. Geological Survey, Water Resources Division. Experience of several years has shown that vegetation and drainage determinations can be made with much greater accuracy. Experimental use of black and white infrared has indicated an even greater ability to complete stream channels further upstream and to find a greater number of the less obvious drains.

With the use of Anscochrome D/200 aerial photographs taken at 5,000-foot flying height with an RC-8 Wild Aerial Camera, 9- by 9-inch format, all of the underwater detail of the Florida Everglades was shown in full color. From the size and shape of the hammocks, the direction and magnitude of the stream flow can be determined. The vegetation color on the hammocks also indicate which are above water at certain seasons of the year.

Other color photographs for the U. S. Geological Survey by the Coast and Geodetic Survey have been made near the coastline of Florida, where the salt water begins to encroach upon the fresh water flow. Mangrove trees are easily spotted on color photographs. Since mangrove grows in salty or brackish water, this gives an excellent indication of the limit of salt water penetration of the Everglades. Water studies are being made in connection with the establishment of a National Park on the Florida Keys, north of Key Largo (10).

10. U. S. Forest Service, Forest Insect Research Division, Department of Agriculture.

a. Insect Damage Detection. In the summer of 1946, U. S. Forest Service was requested to attempt aerial color photography of yellow pine killed by beetles. With the use of a Fairchild K-3-B camera at 2,000-foot flying height, affected trees could be located on the photographs from 3 miles distant. A K-22 camera with a 9- by 9-inch format and a 12-inch focal length lens was also used with satisfactory results. In 1947, aerial color photos were exposed at 10,000 feet with an $8\frac{1}{4}$-inch focal length, 7- by 7-inch format, Fairchild K-3-B camera over St. Joe National Forest in North Central Idaho in order to locate tussock moth damaged timber. Practically every damaged tree could be detected in the color photographs; the transparencies were largely responsible for immediate and all-out efforts to control the infestation of the tussock moth. A large-scale program eradicated the moth and saved millions of dollars in timber.

In late summer 1949, oblique aerial color photography was successfully employed to detect blister-rust damage at St. Joe National Forest (11). In another infested area, the Black Hills, South Dakota, a serious infestation of bark beetles had occurred, and it was necessary to locate every single infested tree. With aerial photographs in color, the interpreters located every possible infested tree, circled the areas on the photographs, and fitted the photographs to maps of the area. Ground crews were given the colored transparencies mounted on Mylar to diffuse the reflected light. Thus the ground crews could more easily find their way than if they were to use black and white photographs.

b. Natural Resources Survey. In order to conduct a national natural resources survey, the U. S. Forest Service must be able to identify tree species, height, and trunk diameter. Using a 6-inch focal length, 70-millimeter format aerial camera, the Forest Service is conducting extensive aerial surveys with Kodak Ektachrome film. The identification of tree crowns for species determination is 15 percent more accurate than that achieved with panchromatic photography. Although the Department of Agriculture is not committed to the use of aerial color photography, the Division of Forest Insect Research is employing this means continually for species determination, tree disease location, and forest inventory. Forest Insect Research does its own flying, photography processing, and interpretation.

11. Florida Department of Agriculture. Several of the state agriculture departments are conducting programs for detection of disease and insect infestation. Notably, work has been done by the Florida Department

of Agriculture in using Ektachrome Infrared photography as an indicator of disease and decline in citrus trees (12). Because of the reflective properties of leaf structure on healthy broad-leaved trees, which yield a high infrared reflectance, diseased trees whose leaves yield a low infrared reflectance are more quickly detected on Ektachrome Infrared photography than by ground observation.

12. California Department of Agriculture. The University of California School of Forestry (13)(14) has worked with aerial photography in cooperation with the California Department of Agriculture and the U. S. Department of Agriculture in the following areas using color photography.

a. Inventory of livestock for the Statistical Reporting Service of the U. S. Department of Agriculture.

b. The species composition and density of range vegetation can be readily determined from aerial color photographs and Ektachrome Infrared photographs.

c. The detection of crop diseases.

13. Sport Fisheries and Wildlife Bureau, U. S. Fish and Wildlife Service, Department of the Interior. Wildlife managers are concerned principally with management and manipulation of the environment. Aerial color photographs permit a wildlife manager to understand the composition, density, and distribution of wildlife cover; the depth or water quality of a lake or stream; the extent of erosion or siltation; and the type and amount of pollution in relation to fish and wildlife.

a. Inventories. Before 1962, the population of whistling swans wintering in Chesapeake Bay had to be inventoried by an observer and a pilot in aircraft by counting and estimating the number in flocks as well as young and adult. Aerial color photography was used after 1962 and found superior to black and white because the young could be more readily distinguished from the older birds in color than in black and white photography. Inventory of swans has now become a one-man pilot/photographer operation.

b. Migratory Fish Movement. Color photographs have been used to study the movement of salmon up the Western streams for spawning, as well as marine mammals on and near offshore islands.

14. Department of Health, Education, and Welfare. Pollution of ocean, lake, and river waters is a matter of deep and growing concern to all elements of our society. Aerial photographs in color provide a means of detecting and monitoring the purity of our national water supply. Effluent and algae resulting from changes in available dissolved oxygen and changes in water temperature can be observed.

15. Acid Mine Drainage Program, Federal Water Pollution Control, Department of the Interior. An area of growing concern is the formation of acid mine water from a reaction of pyrite-bearing formations (associated with coal) with water and oxygen. The product of the reaction is iron sulfate and sulphuric acid. The sulfate emerges from the mine and undergoes a second reaction to form iron hydroxide and more sulphuric acid. The iron hydroxide termed "yellow boy," a bright orange precipitate, coats stream banks and bottoms. The use of aerial color photography is helpful in determining effluent points, flow patterns, and seepage areas (15).

16. Bureau of Public Roads, Department of Commerce. Aerial photography has been used extensively in highway location and design for many years. However, expert use of the data supplied by black and white photography requires the ability to differentiate between the various shades of gray which limit the discrimination of soil types.

Not only the U. S. Bureau of Public Roads, but the many State Highway Departments are using aerial color photography because of the ability of interpreters to interpret with more confidence, soil and vegetation information which is needed to plan and design highways.

17. U. S. Air Force, Department of Defense. Extensive experimentation and development have been performed by the U. S. Air Force in the use of aerial color photography for strategic and tactical operations. Because of the classifications of these efforts, it can only be reported that the applications for aerial color photographs to specialized needs follow generally their use by civilian agencies mentioned previously. Aerial color photographs are being used experimentally for terrain evaluation, target determination, and reconnaissance. Extensive use awaits state-of-the-art hardware development.

18. U. S. Navy, Department of Defense.

a. Reconnaissance. The U. S. Navy has experimented with color photography for the detection of dye markers dropped into the water. Dye markers are used to locate submarines, sunken vessels, or hazards to

navigation. The Naval Reconnaissance and Technical Support Center is testing the employment of aerial color photography and Ektachrome Infrared color photography as a means of penetrating the haze which often covers coastal areas (Fig. 24).

b. Charting. Because of superior water-penetrating quality of color photography, experimentation is proceeding in the employment of aerial color photography for determining shoreline depths and shallow water ocean bottoms.

c. Buoy and Marker Location. Similar work to that of the Coast and Geodetic Survey, Environmental Science Services Administration, is being done by the Oceanographic Office, U. S. Navy, in locating buoys and markers by means of aerial color photography (Fig. 25).

19. U. S. Army, Department of Defense.

a. Reconnaissance. Occasional missions are flown for reconnaissance using color aerial photography; however, color missions are not a standard operation as compared to aerial photographic missions flown with black and white panchromatic photography.

b. Mapping. Experimentation in military employment of aerial color photography for mapping is in the research and development stage. Full feasibility appears to be indicated. Hardware must be developed and tested for an operational system. Figure 26 represents the quality of aerial photography which would be used for mapping.

20. National Aeronautics and Space Administration. Hyperaltitude and orbital photography has been obtained from space since the first sounding rockets were sent aloft in 1946. The full impact of earth's colorful terrain was not realized until the extraordinary color photographs were returned from the Gemini IV mission in 1965. Previously, it had been theorized that satisfactory color photography could not be obtained from orbiting satellites because of the earth's atmosphere and light scattering. However, the earth's atmosphere has acted as a translucent sheet in contact with the surface, thereby permitting transmittance of a considerable part of the spectrum. Light scattering caused chiefly by suspended particles of water and other substances (Mie effect) is strongly dependent upon the wavelength of light being transmitted. Orbital color photographs taken over Southwest United States and the African dry areas are more successful than those taken over the Gulf Coast of the United States and the Amazon Delta.

a. Cameras. The cameras which have been used with success on the Mercury flights were the Hasselblad 500C and the Maurer Space Camera. They were hand-held and pointed toward earth through the capsule windows. On several occasions, photographs were taken outside of the capsule but the cameras were still hand-held.

b. Emulsions. Ektachrome and Super Anscochrome as well as Ektachrome Infrared (false color) film with and without filters have been employed.

c. Altitudes. The majority of the successful color photographs obtained in the Gemini experiments were obtained at altitudes from 100 to 200 statute miles. On a special Gemini II flight, photographs were taken at altitudes of 400 to 850 statute miles.

d. Availability of Color Photography Coverage. According to Lowman (16), color photography contains far more information for geologic purposes than panchromatic photography, but has not been used extensively because of higher initial cost of film and processing. However, this is a negligible factor when the total cost of obtaining orbital photography is considered. Color distortion has been a consistent problem in orbital photography and is stronger in the blues and blue-green wavelengths of light which are most characteristic of humid areas such as the Gulf Coast of the United States, the Caribbean Sea, and other low-lying humid areas. Browns, reds, and yellow are predominant in arid areas such as the southwestern part of the United States, the African Desert, and the Arabian Peninsula.

e. Specific Uses of Color Photography (National Aeronautics and Space Administration.)

(1) Soil Erosion. The color and distribution of the turbid effluent from large rivers such as Siang River in China have been photographed on a number of Gemini missions. The effluent pattern over several thousand square miles is distinct because of the difference in color (Fig. 27).

(2) Shoreline Bottom Mapping. A study of a color photograph of the Colorado River mouth in Baja, California clearly indicates the changing bottom caused by runoff in the river (17) (Fig. 28). Because of the correlation between water color and depth, a rough check of hydrographic charts can be made.

Fig. 24. Dye markers in Gulf Stream off Ket West, Florida.

(U. S. Navy photograph.)

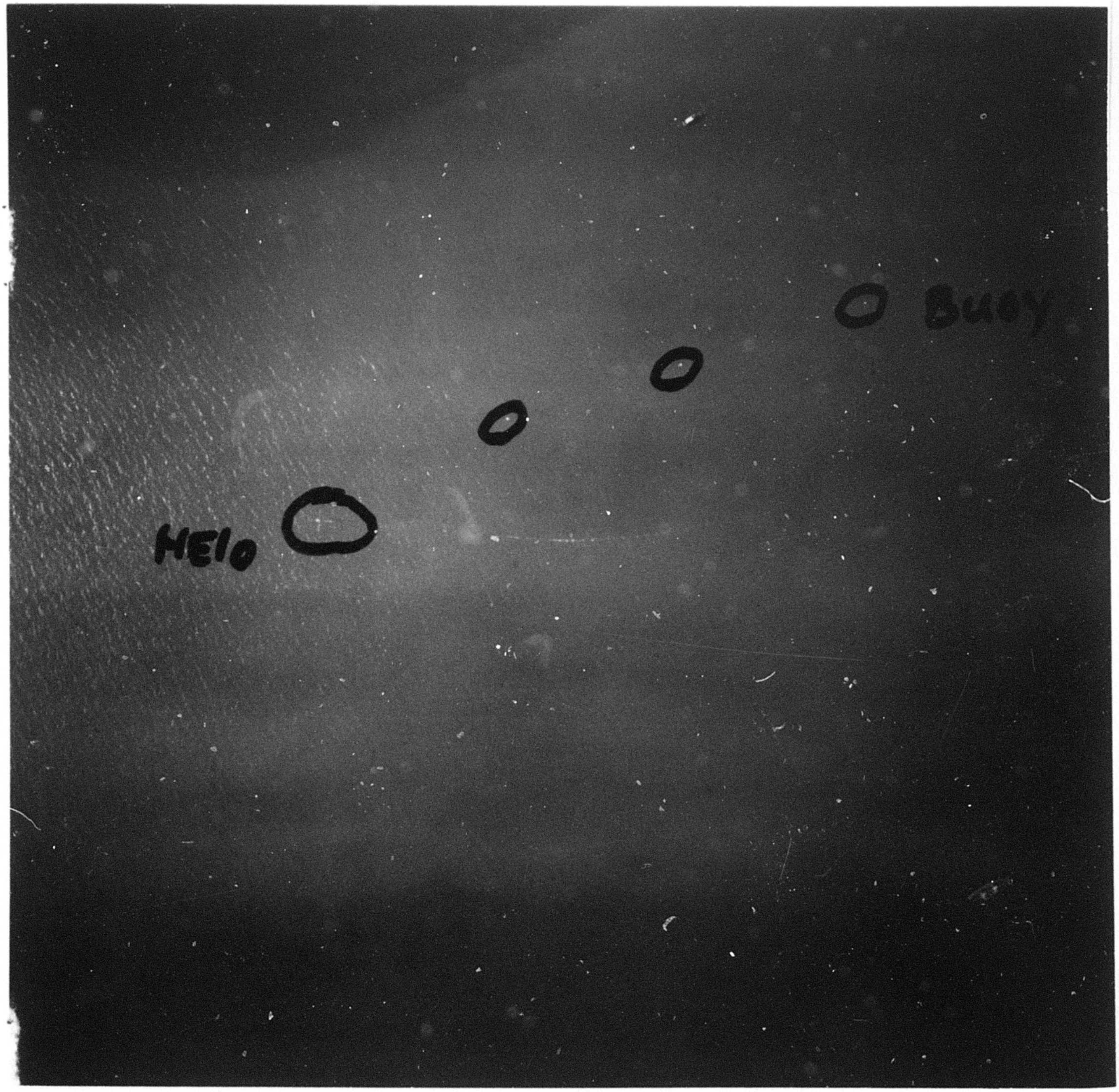


Fig. 25. Helicopter and buoys in Gulf Stream off Key West, Florida.

(U. S. Navy photograph.)

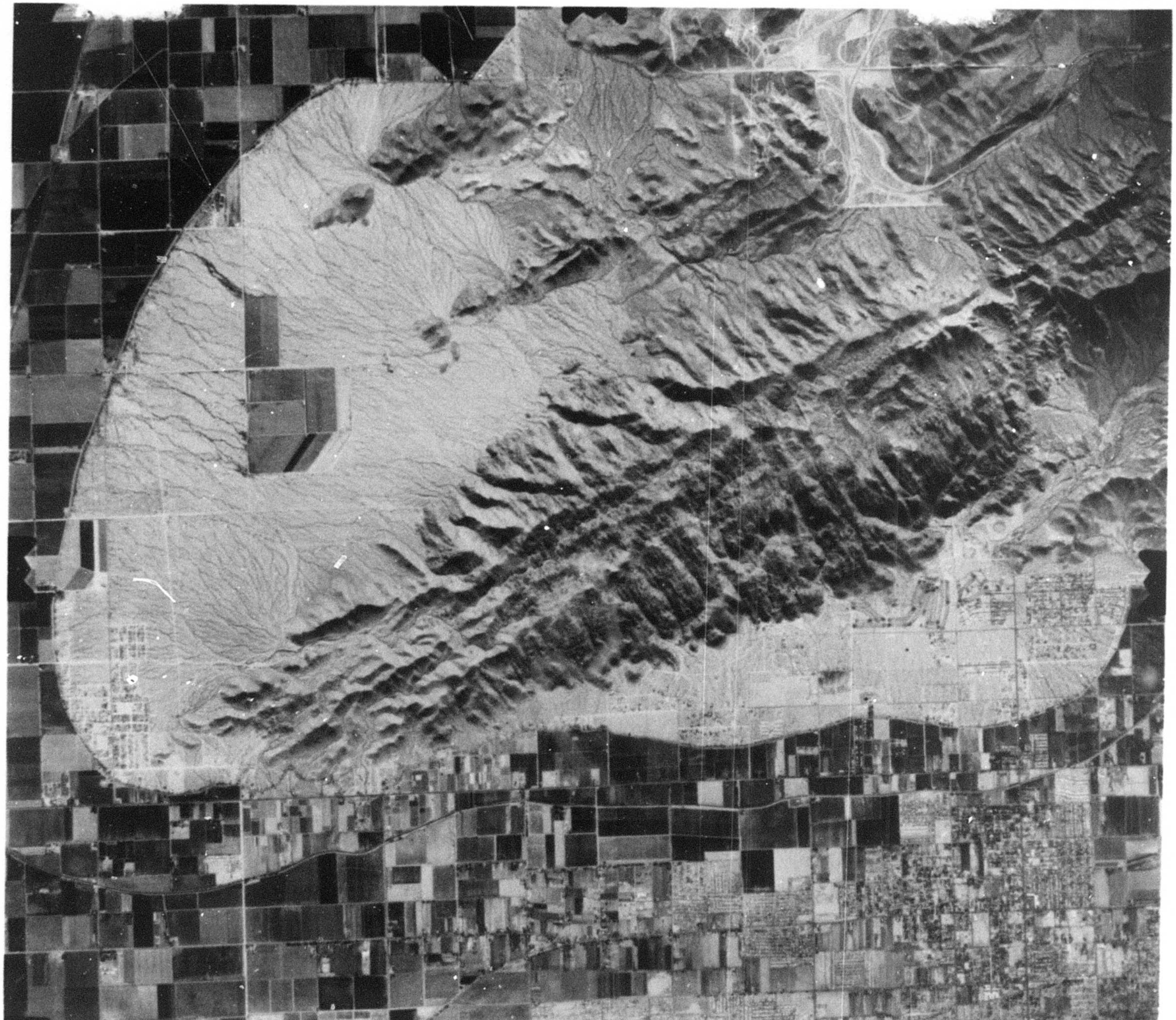


Fig. 26. South Mountain, Phoenix, Arizona. (U. S. Air Force photograph.)

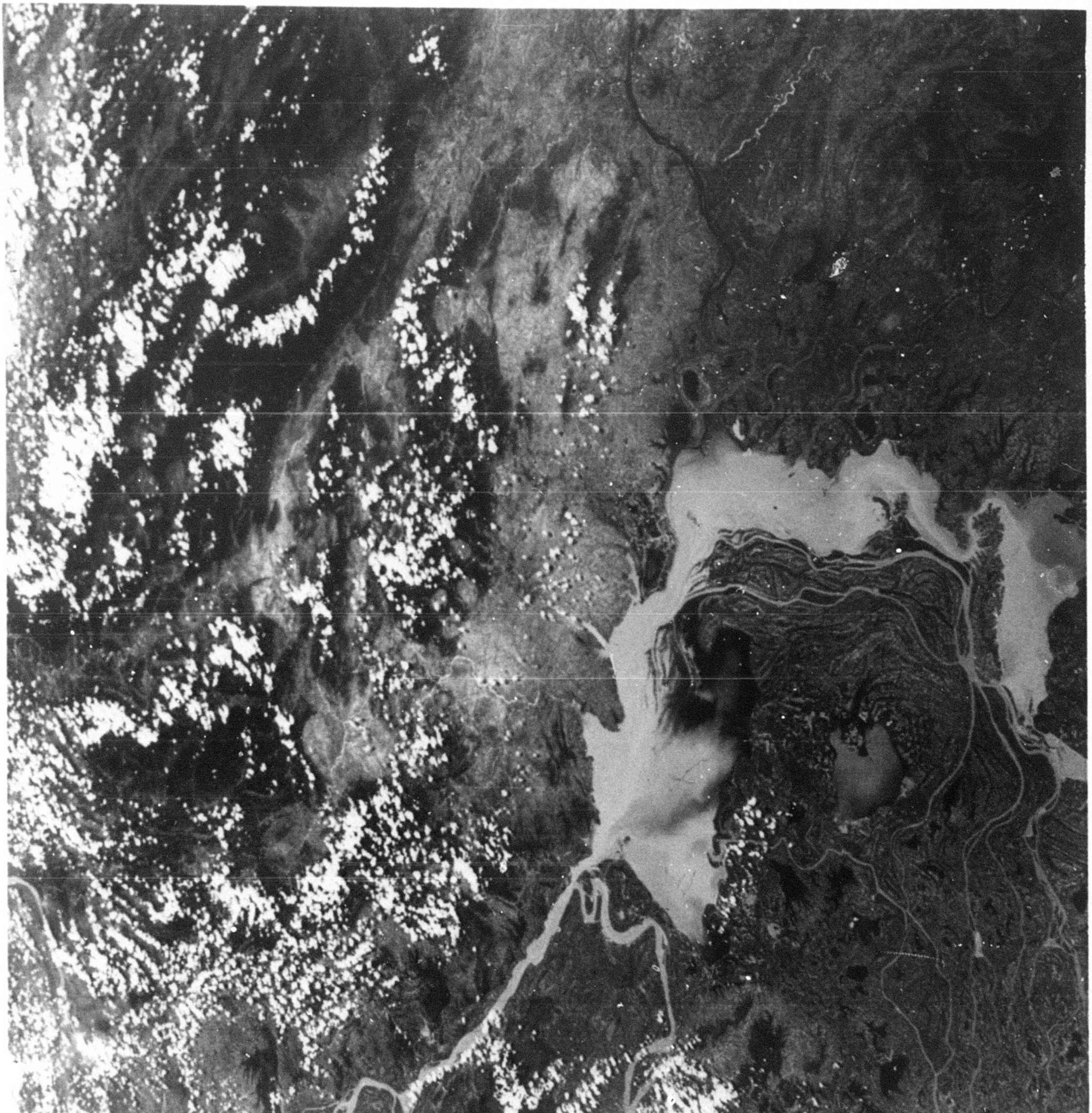


Fig. 27. China, Hunan and Hupeh Provinces. Tung Ting Hu (lake) and the Yangtze River flowing northeast. The Siang River flows into the lake from the south. (National Aeronautics and Space Administration Gemini V photograph.)

Fig. 28. Mouth of Colorado River and Gulf of California. (National Aeronautics and Space Administration Gemini IV photograph.)

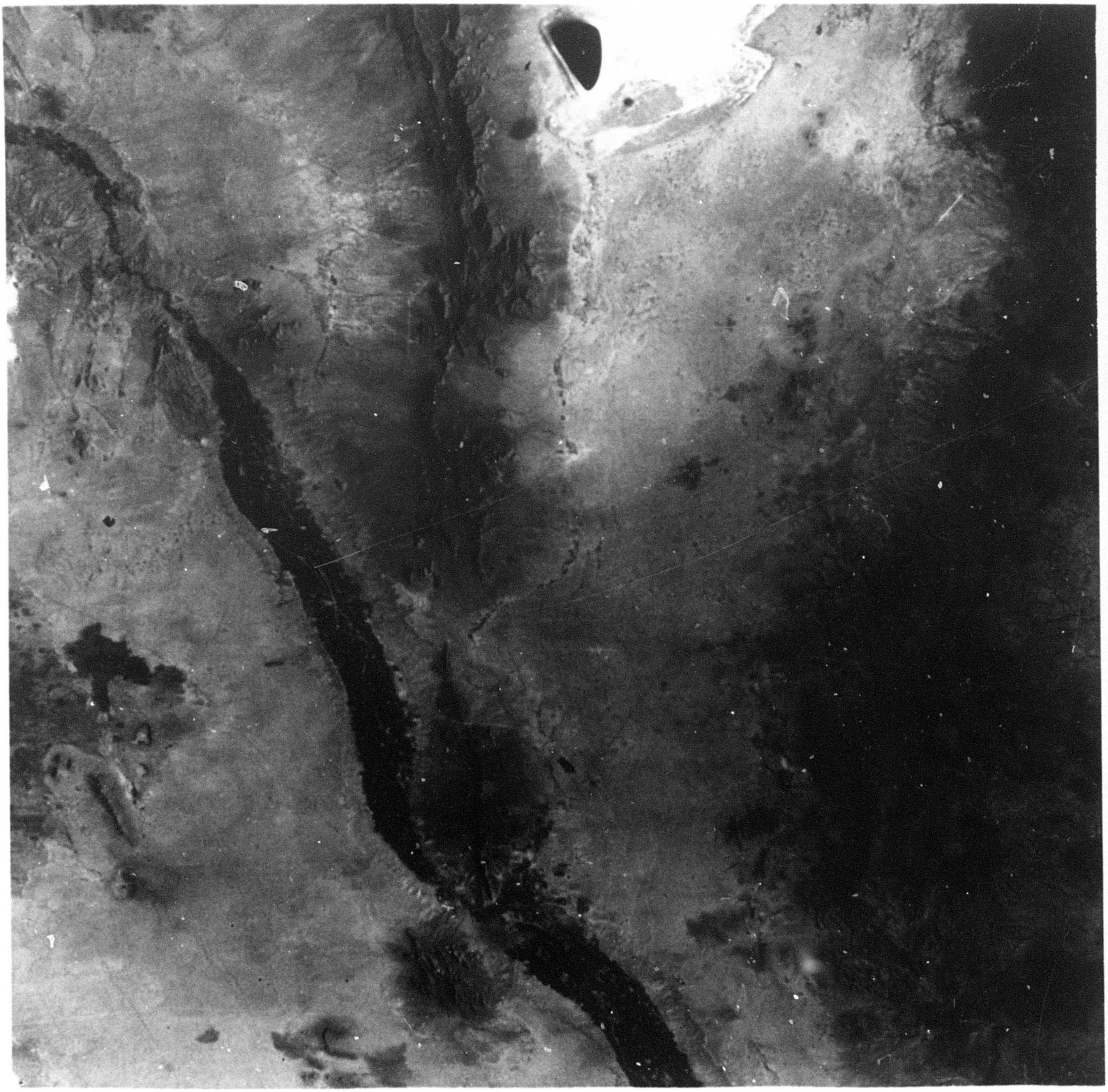


Fig. 29. Rio Grande; El Paso, Texas; and Ciudad Juárez, Mexico. White Sands National Monument at north edge of photograph. The Sacramento Mountains are to the east and the San Andres Mountains are in the center. Railroads running northeast and northwest from El Paso are visible. (National Aeronautics and Space Administration Gemini V photograph.)

(3) Geology. The availability of color coverage of large arid regions (Fig. 29) permits study of entire zones of pedimentation. New evidence supporting the view that red sediments were formed chiefly in arid regions has been discovered by T. R. Walker (16).

(4) Forestry. Orbital color photographs can indicate the onset of timber disease by the change in appearance of vegetation color and can also be used for inventorying timber resources.

21. Combined Interagency Aerial Color Photography Tests. In 1964, the American Society of Photogrammetry organized a committee on aerial color photography, whose stated purpose was to evaluate the role of color, infrared, and special-purpose films in photogrammetry. With excellent cooperation from the Defense Intelligence Agency, U. S. Air Force, Corps of Engineers, Coast and Geodetic Survey, U. S. Geological Survey, U. S. Forest Service, Army Map Service, Army Engineer Topographic Laboratories, Eastman Kodak Company, General Aniline and Film Corporation, and Fairchild Camera and Instrument Corporation, several field tests were completed with varying degrees of success.

22. Bennettsville, South Carolina, Field Test.

a. Test Method. A test plan for comparison of color and black and white photographs was prepared by the American Society of Photogrammetry Color Aerial Photography Committee. A U. S. Air Force RC-130 aircraft was equipped with a pair of cartographic cameras with 6-inch focal length lenses and 9- by 9-inch formats. One camera was an RC-8 Wild camera with an Aviogon achromatic lens; the other camera was a Fairchild KC-4 with a Geocon achromatic lens, Panchromatic black and white film (Plus-X), Ektachrome MS (color), and Ektachrome Infrared (false color) films were supplied by Eastman Kodak Company; Anscochrome (color) was supplied by General Aniline and Film Corporation. The films were alternated in the cameras so that comparative film data were obtained independent of camera bias. The test site, approximately 30 square miles (Fig. 30), included the city of Bennettsville, South Carolina (18). Army Map Service engineers working in the area obtained the following requested ground data for 42 control points selected from the aerial photography (Fig. 31):

(1) Vegetation (tree height, spacing, ground cover).

(2) Type of soil (gravel, rock, sand, clay, silt, mixtures).

(3) Moisture Content (wet, dry, marsh, flooded, surface drainage).

(4) Crop identification (cotton, corn, wheat, etc.)

(5) Culture (type of structure, purpose).

A detailed analysis plan was prepared by the Army Engineer Topographic Laboratories for photointerpretation work performed by interpreters at the Data Analysis Center, Itek Corporation. The interpreters were requested to prepare the following:

(1) A drainage map including primary, secondary, and tertiary drainage.

(2) A vegetation map, differentiating series within interpretation capabilities.

(3) A soils map for the identification of similar soils areas with a key for each area.

(4) A culture map identifying roads, railroads, and special-purpose buildings.

Interpretations were performed for the 10,000-foot photography. The interpreters were not given the ground truth, nor could they compare one set of photographs with the other two. In effect, there were three separate sets of interpretations, made first from the panchromatic photography (Fig. 32), next from the color photography (Fig. 33), and finally from the Ektachrome Infrared (false color) photography (Fig. 34).

In addition to the above maps, the interpreters were requested to make their analysis of each of the 42 selected control points, supplying the same information which had been requested from the field engineers.

Upon completion of the project, the Data Analysis Center, Itek, supplied thirteen 1:20,000 scale maps, one each of drainage, soils, vegetation, and culture for each emulsion studied, in addition to interpretations of the 42 points also for each emulsion.

b. <u>Test Results</u>. A visual comparison of the overlay maps prepared by the photointerpreters revealed an increasing amount of drainage

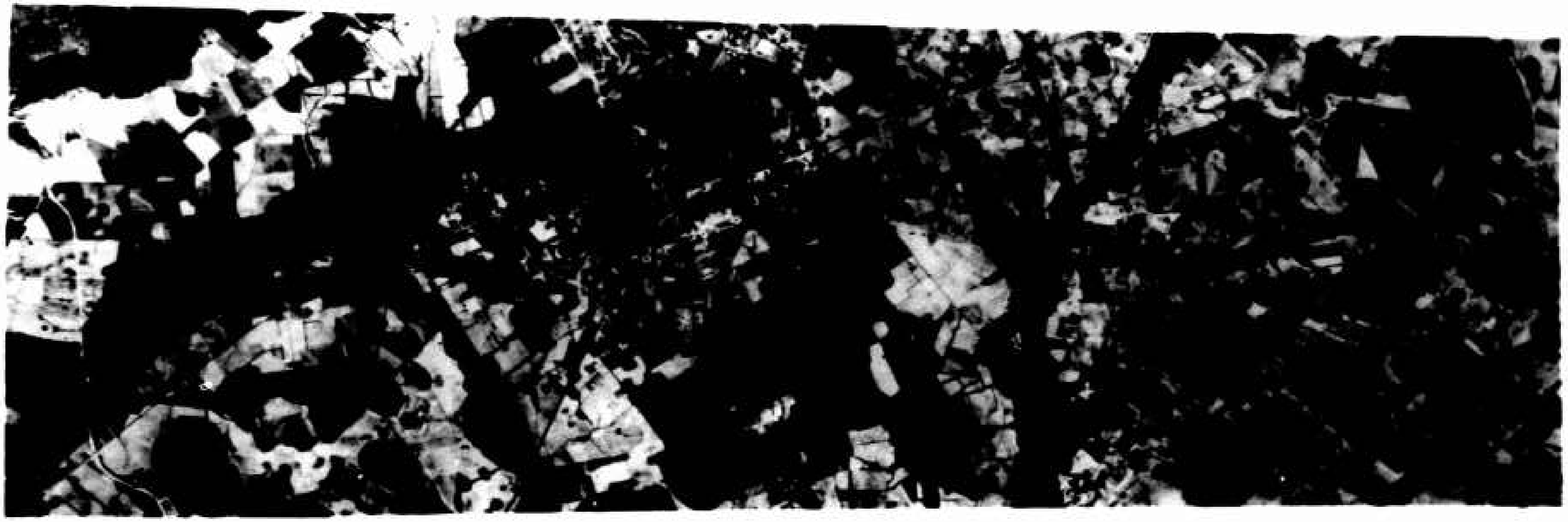


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Fig. 30. Bennettsville, South Carolina, test area.

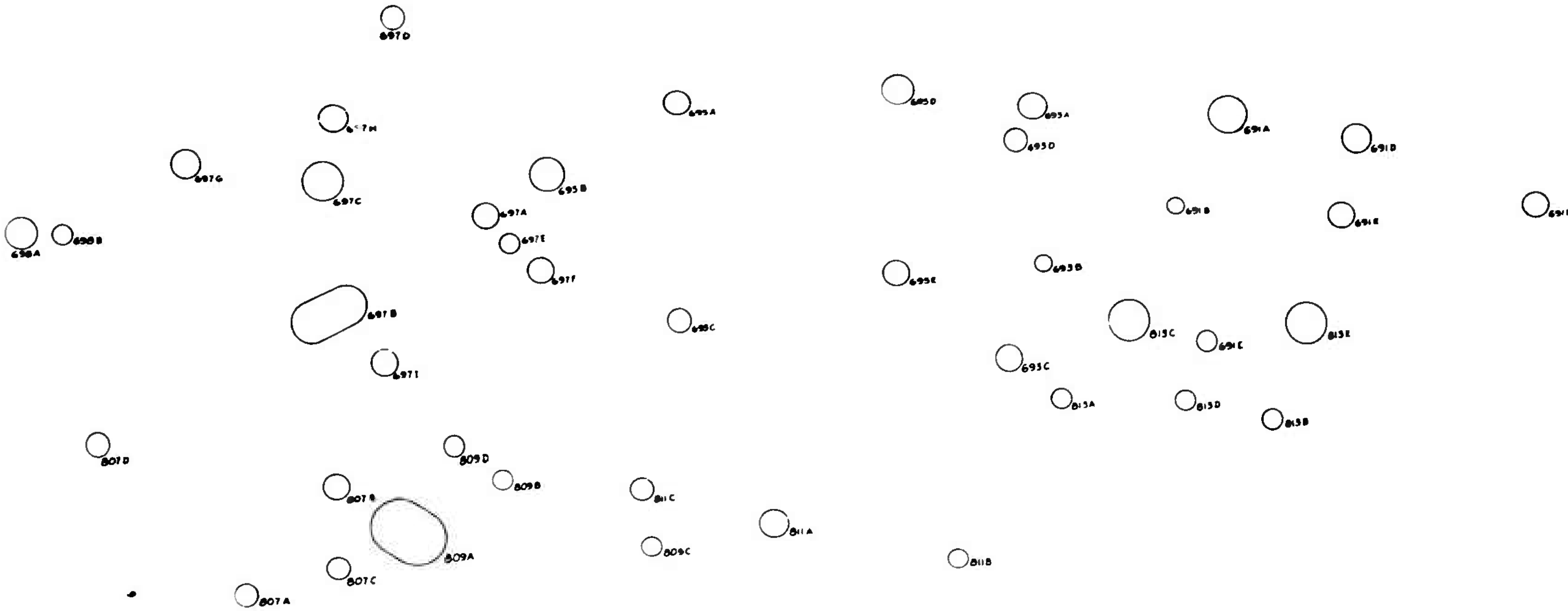

Fig. 31. Descriptive points and ground stations, Bennettsville, South Carolina.

density mapped from panchromatic (Fig. 35), color (Fig. 36), and Ektachrome Infrared (false color) (Fig. 37), in that order. In the interpreters' opinion, Ektachrome Infrared film afforded a rapid and accurate means of mapping not only drainage but also moist soils. Streams and ponds appeared black, dark brown, or blue depending upon the amount of sediment in the water to reflect the infrared spectrum. Lack of sediment was indicated by the maximum absorption of infrared; silted waters registered as a lighter tone. Tertiary and intermittent drainage lines were readily observable since the presence of moisture contrasted with the highly reflective dry soil.

Vegetation maps compiled from panchromatic black and white photography, which had less contrast than color photography, had less detail, and the vegetation maps compiled from the Ektachrome Infrared photography indicated more detail than the other two. The Ektachrome Infrared photography easily discriminated between deciduous and coniferous trees, crops, and grassland, based again upon the infrared reflectivity of the the vegetation. Broad-leaved trees radiated more reflectivity than the narrow needle coniferous variety. Merest beginnings of crop growth which showed as red traces against the blue soil, or as green against brown in color, could be more rapidly perceived than those in tones of gray on the panchromatic film (Fig. 38).

A comprehensive soils study would have required a field trip by the photointerpreters; therefore, they were requested to prepare their soils map by using a set of keys in which the soils were differentiated by area. The color maps and false color maps provided the maximum number of detailed areas in which areas of similar color were matched in symbol (Fig. 39).

No geologic structures, folds, or faults were observed in any of the three types of photography studied. The major landforms of the area were characterized by low relief, slightly hummocky, and much of the surface topography was probably deeply underlaid by unconsolidated sand and gravel as evidenced by the numerous excavations and pits throughout the area.

For culture identification and determination, color photography was more satisfactory in respect to speed and confidence (Fig. 40).

A visual comparison of all of the maps prepared for this study indicated that the same information was observable on the color and false color (Ektachrome Infrared) films, whereas less information was interpreted from the panchromatic black and white photography. The

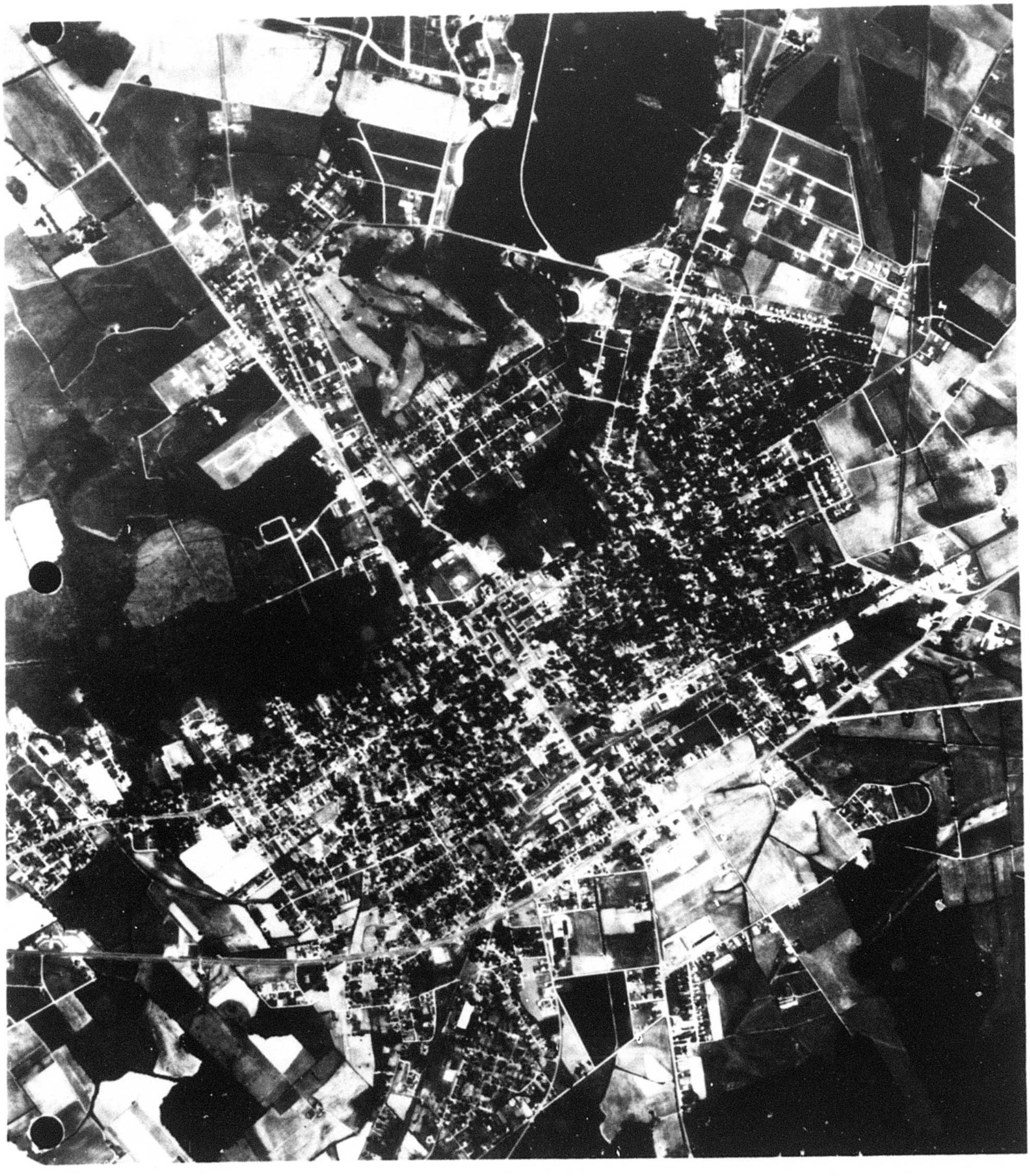

Fig. 32. Bennettsville, South Carolina, panchromatic Plus-X photograph.

Fig. 33. Bennettsville, South Carolina, Anscochrome photograph.

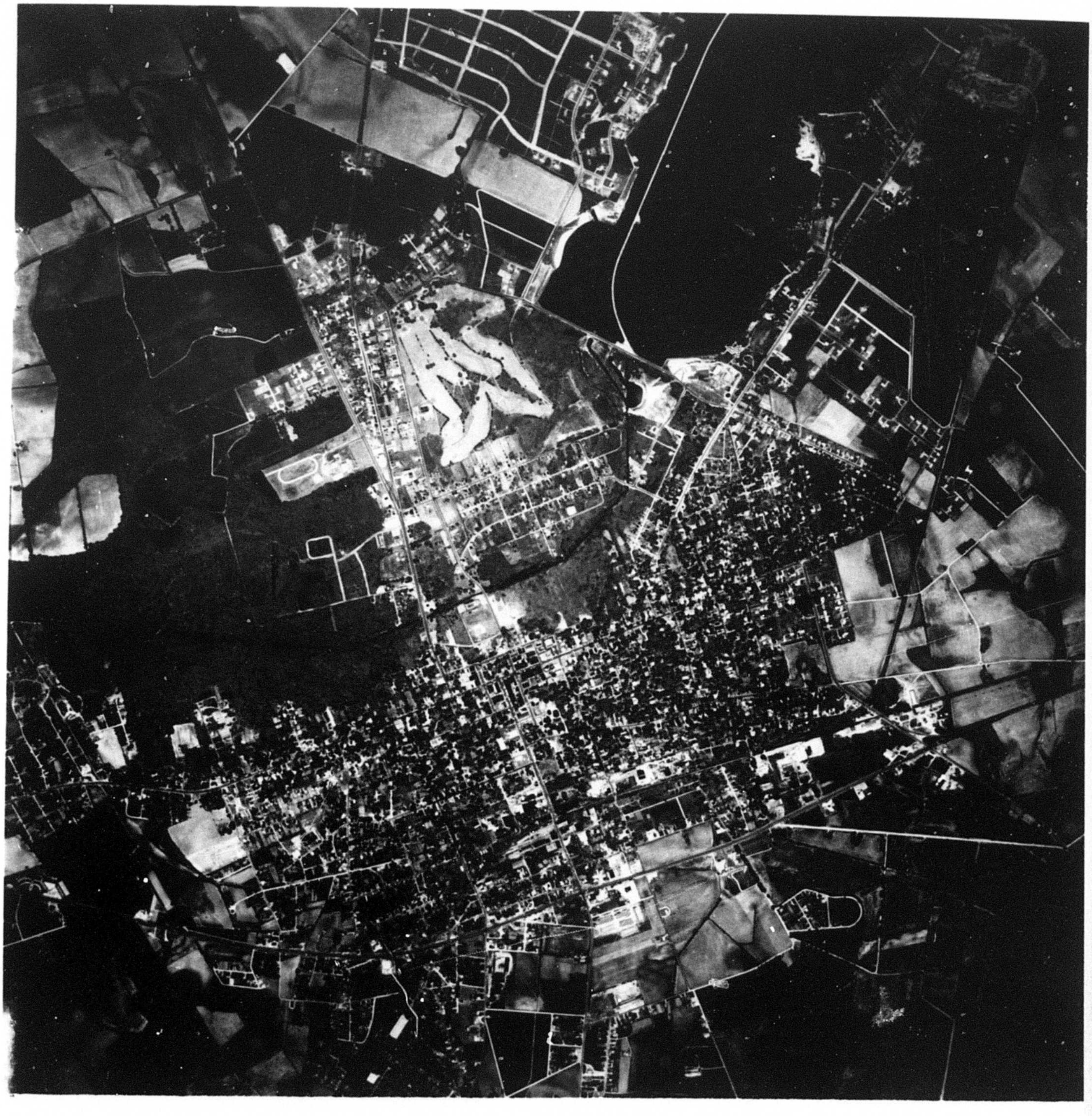

Fig. 34. Bennettsville, South Carolina, Ektachrome Infrared photograph.

Fig. 35. Drainage map, Bennettsville, South Carolina, from panchromatic photographs.

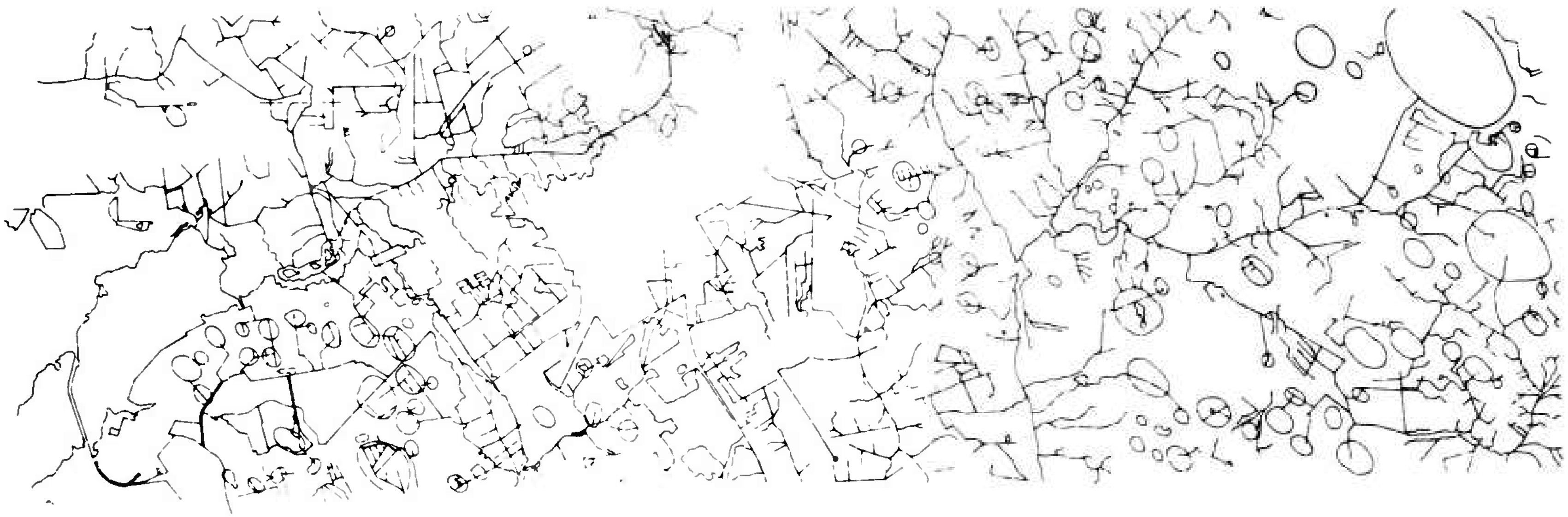

Fig. 36. Drainage map. Bennettsville, South Carolina. from color photographs.

Fig. 37. Drainage map, Bennettsville, South Carolina, from Ektachrome Infrared photographs.

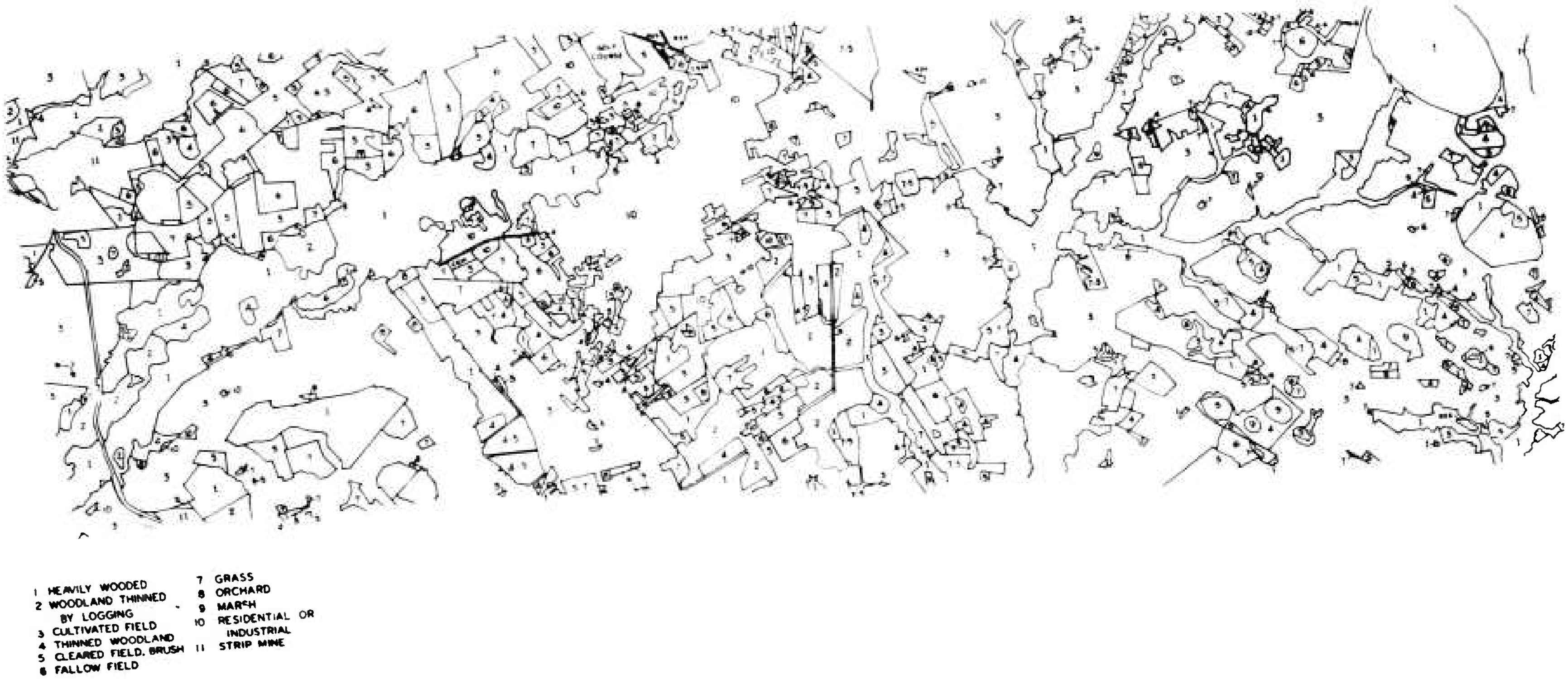

Fig. 38. Vegetation map, Bennettsville, South Carolina, from color photographs.

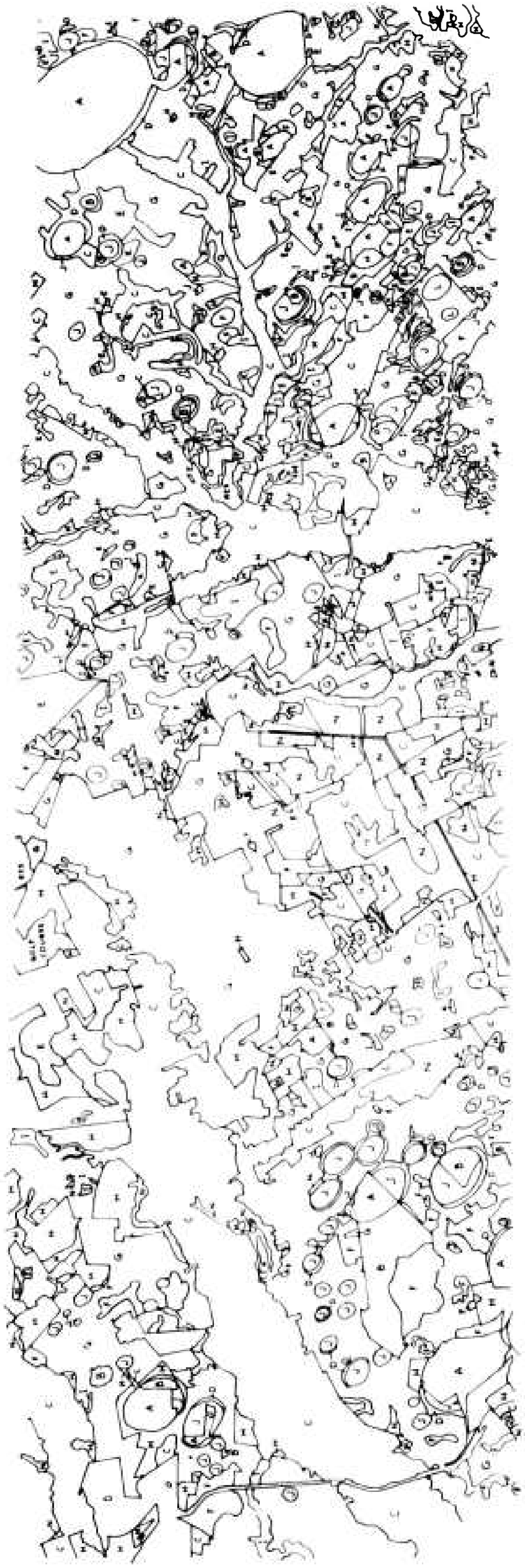

Fig. 39. Soils map, Bennettsville, South Carolina, from color photographs.

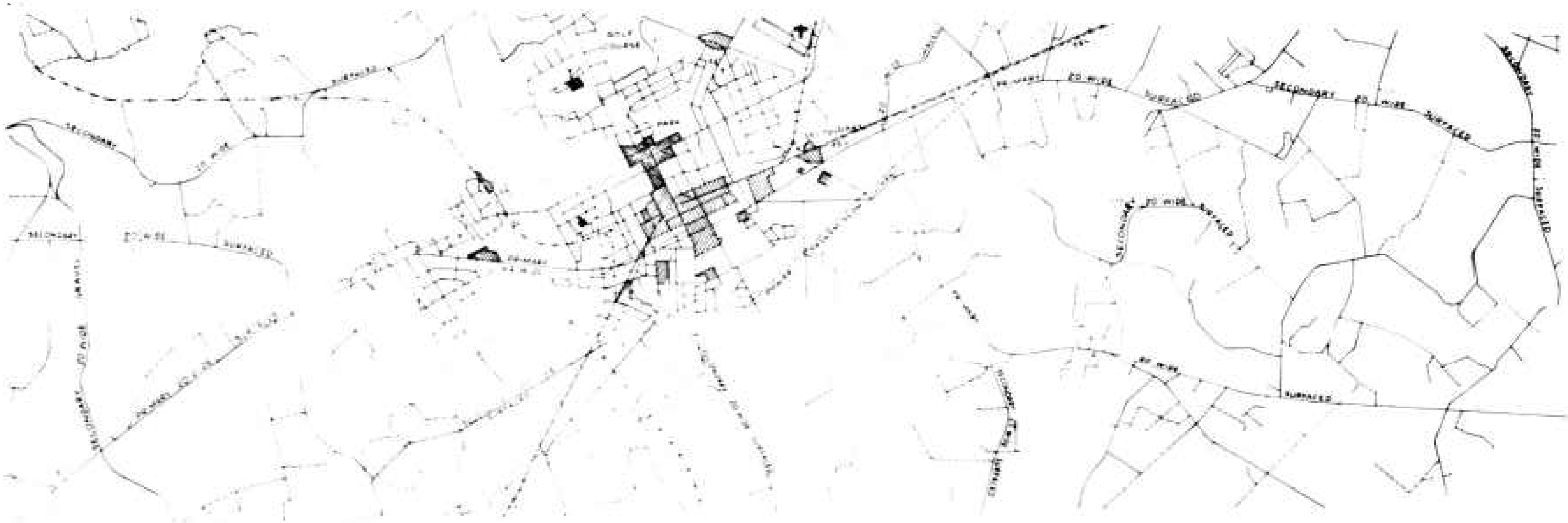

Fig. 40. Culture map, Bennettsville, South Carolina, from color photographs.

photointerpreters also found that working with aerial color photography or Ektachrome Infrared photography was more satisfactory regarding the speed of differentiation and the confidence level of the interpretation.

Each of the 42 preselected photograph points was studied independently with the following results:

237 items requested - 136 correct for panchromatic
163 for color
165 for color infrared

The ratio of incorrect to correct was 69/136 for panchromatic.

The ratio of incorrect to correct was 47/163 for color.

The ratio of incorrect to correct was 45/165 for color infrared.

The correct responses were approximately 20 percent greater for color film than for panchromatic film and 22 percent greater for Ektachrome Infrared film than for panchromatic film. Conversely, there were fewer errors for color photography than for items extracted from black and white photography. The speed of interpretation may be higher for infrared. The significance of the additional detail acquired in each step should be considered for proper weighting of the gain in percent.

To sum up the interpretive work performed on the three emulsions and the three sets of photography used in this test, color fidelity was one key to the interpretations, whereas color bias, which lent a predominantly green or blue tone to some photographs because of exposure or processing, was another consideration. However, color bias is not as important as color differentiation, because the Ektachrome Infrared which is a color distorting medium, known as false color film, was equal to and in some cases better than color film for interpretations. To be more specific, if a patch of vegetation, rocks, soils, or a geological formation differs in hue and chroma from its surroundings, then it has its own specific spectral characteristics which facilitates discrimination and identification (18). If some ground correlation or field work can establish the bias, then differentiation is the working tool.

23. Phoenix, Arizona, Field Test. A rigidly controlled color comparison test was devised by the American Society of Photogrammetry Color

Photography Committee to be flown over the Arizona High Density Control Area which is part of the Phoenix, Arizona, Test Range. The concept of the test plan was that greater emphasis would be placed on ground truth records to be made simultaneously with the aircraft flights, positive identification of ground control points in the photography, and large color panels whose spectral curves were known. The response of the desert soils, vegetation, and rocks themselves would be compared with the color panels. Metric measurements to determine geometric distortion would be made and photointerpretations would be compared with the color panels. Three cartographic cameras would operate simultaneously, and test flights would be flown at three altitudes -- 10,000, 20,000, and 30,000 feet. All tests were to be completed within 1 week after an initial test flight for exposure data.

In addition to the cooperation of the organizations mentioned previously, the National Aeronautics and Space Administration supplied a pair of matched RC-8 cartographic cameras and U. S. Army Engineer Topographic Laboratories furnished the KC-4 Fairchild camera, all three equipped as before with 6-inch focal length, 9- by 9-inch format achromatic lenses. The Data Corporation under contract to the U. S. Air Force prepared four 100- by 100-foot canvas panels painted in epoxy paint -- in red, blue, green, and yellow (Fig. 41). Edge analysis panels 6,400 square feet each in gray and black were installed as well as a pair of T-bar resolution targets each 275 feet long. The High Density Control Area is 20 miles south of Phoenix, in the Gila River Indian Reservation, and the flights were made from 25 June to 2 July 1966. While the three cameras were operating simultaneously in the RC-130 aircraft flying at the specified altitudes, ground truth data such as temperature, humidity, light intensity, and ground control photographs of the control points were being obtained. Horizontal and vertical control points in a 35-square-mile area were recorded on all of the aerial photography by having the control points flagged with 12- by 12-foot sheets of white Kaycel sheeting (Fig. 42).

Numerous tests are being conducted on the resulting photography by several organizations including Army Map Service, Data Corporation, Itek Corporation, U. S. Geological Survey, Coast and Geodetic Survey, and U. S. Army Engineer Topographic Laboratories. Doctor Olin Mintzer, Professor of Civil Engineering at Ohio State University, made a soils analysis of a small area (19).

Nine- by nine-inch glass diapositives of the test were printed from panchromatic photography, color photography, and Ektachrome Infrared photography and given to Professor Mintzer in that order. He was also supplied with a 1:100,000 scale photomosaic in black and white in addition

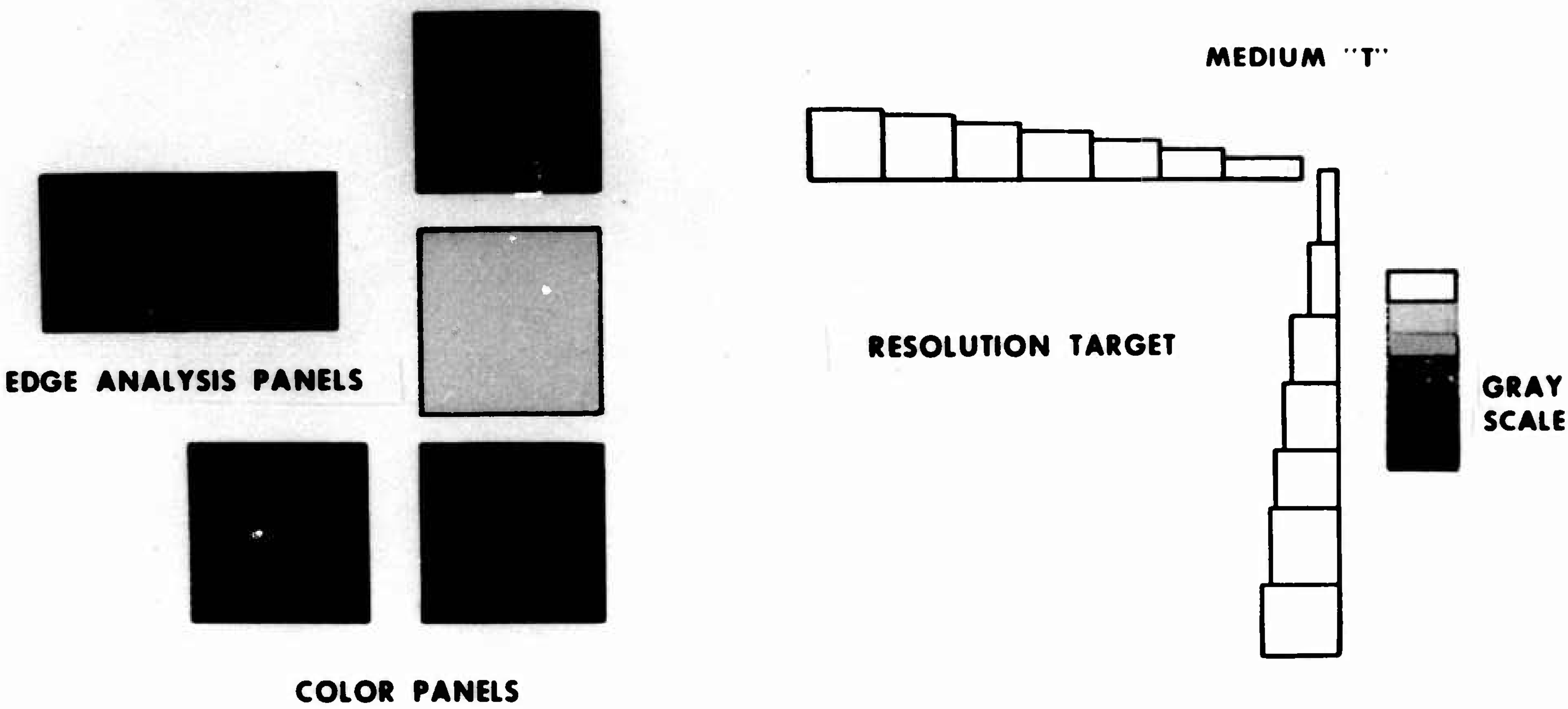

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Fig. 41. Photogrammetric color target test site. Arizona.

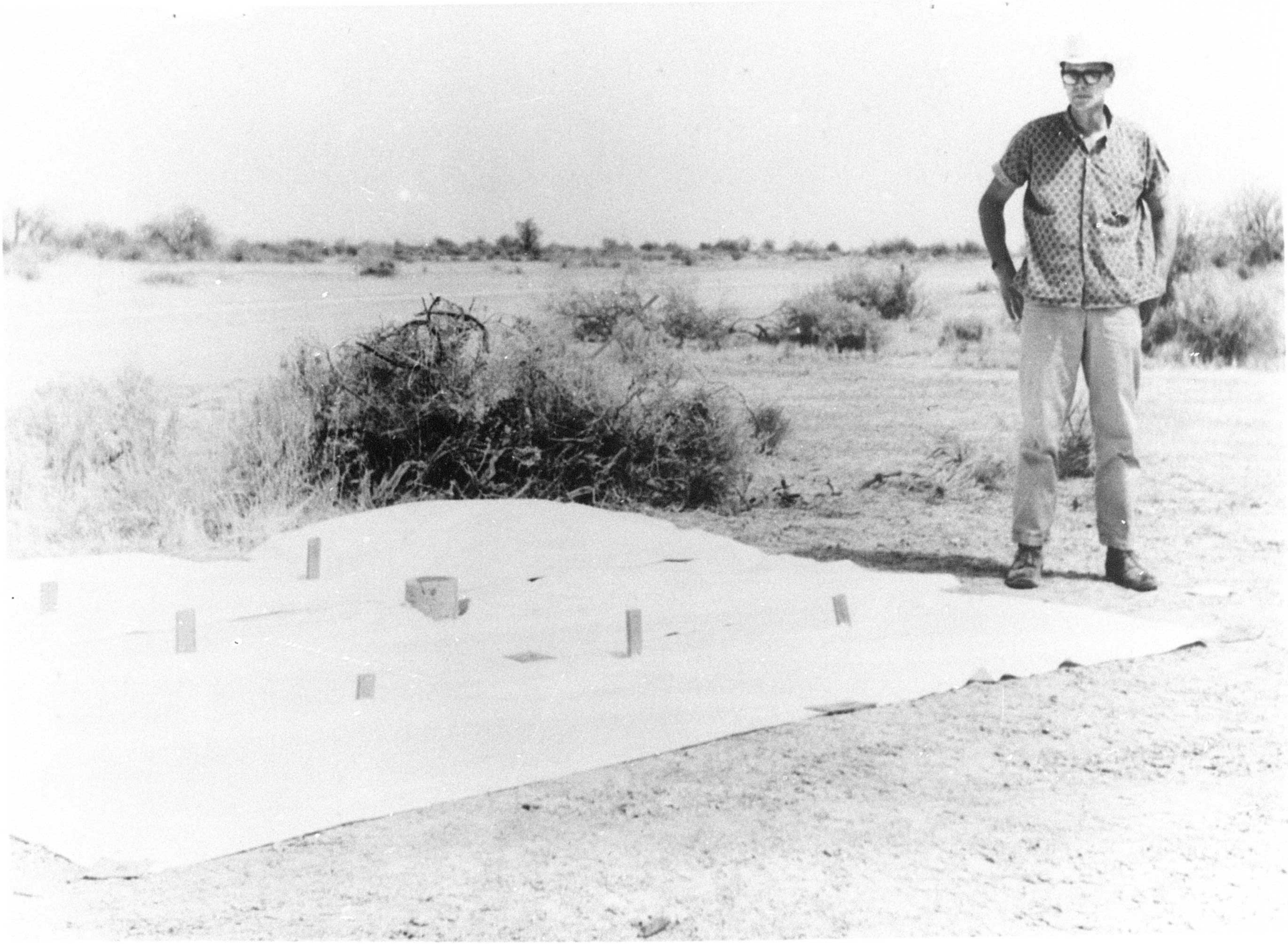

Fig. 42. Control point flagged with Kaycel.

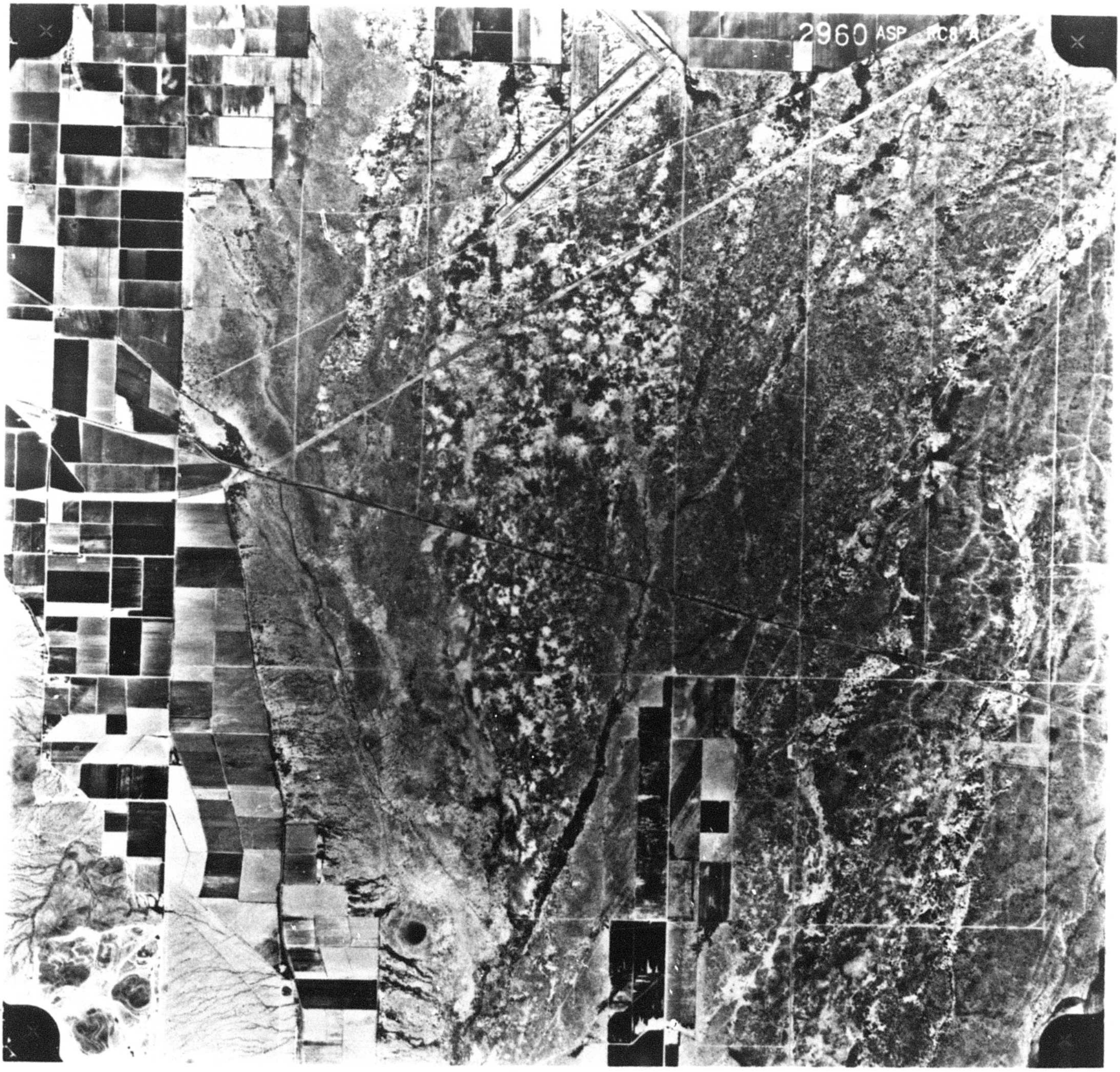

Fig. 43. Phoenix, Arizona, test site, panchromatic Plus-X, color panels in center.

Fig. 44. Phoenix, Arizona, test site, Ektachrome, color panels at right center.

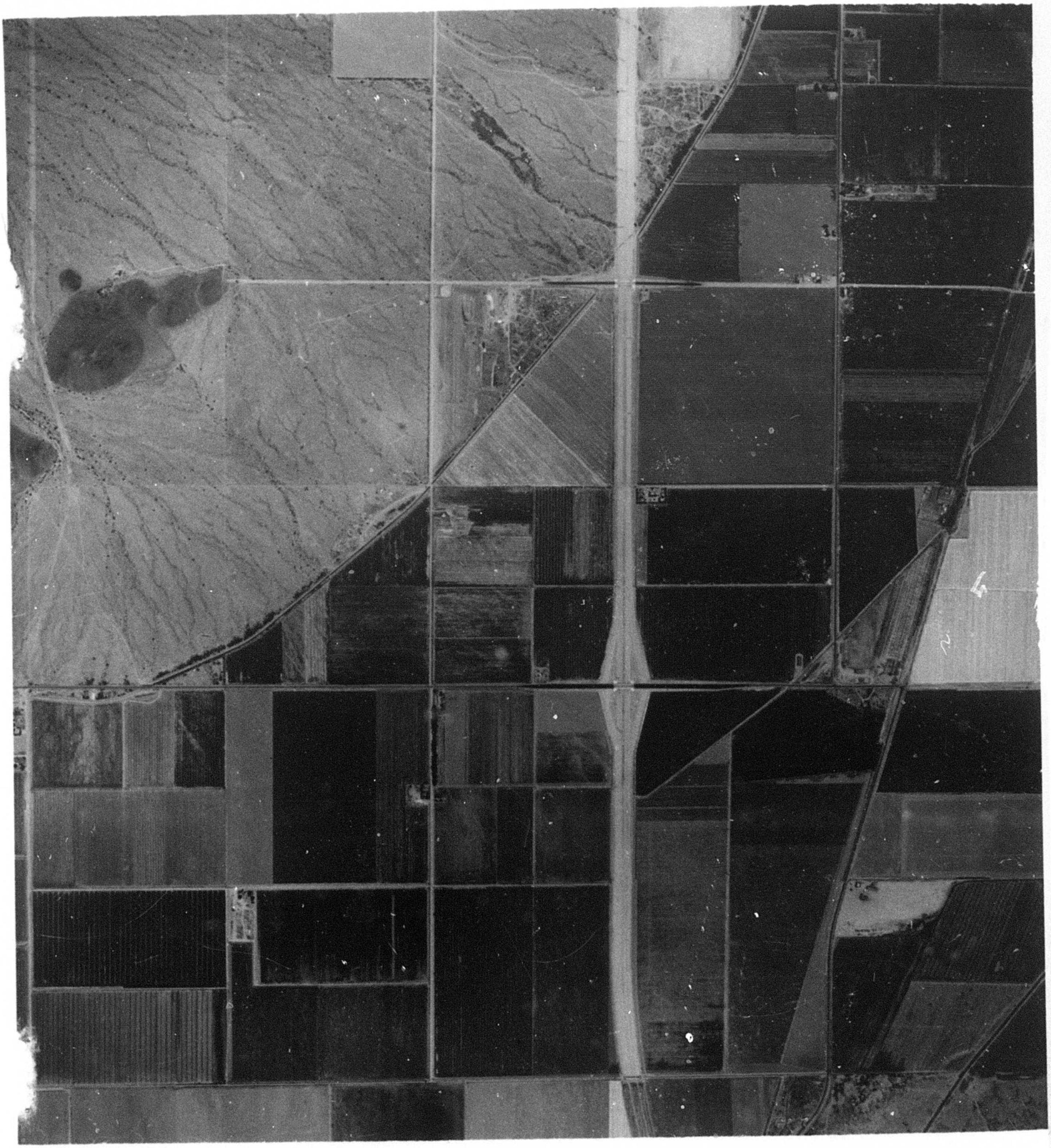

Fig. 45. Phoenix, Arizona, test site, Ektachrome Infrared, field pattern.

to a topographic map. Since Professor Mintzer had never visited the area, his knowledge was general; that landforms were developed as alluvial filled valleys, that the surface materials in grain size were anything from boulders to clay, and that only consolidated materials would be in the hills and buttes scattered throughout the test area. The colors of the test panels were well defined at all altitudes. The vegetation types to be expected were mesquite, salt bush, mustard grass, and cactus. No more information regarding soils or vegetation types was made available. Three stereo models of each of the flight heights (10,000, 20,000, and 30,000 feet) and three films were studied; first the panchromatic Plus-X, then the Ektachrome, and finally the Ektachrome Infrared (Figs. 43, 44, and 45).

The standard terrain data recording format was developed for information associated with soils. The record included: Geologic information, origin, landform, drainage pattern, gully shape and gradient erosional features, phototone, landuse, vegetation, and surface materials. Cultural features were also recorded.

The total time required o perform the photointerpretation and record the natural and cultural features was 48.5 hours; 22.5 hours for the 30,000-foot-altitude photography, 13 hours for the 20,000-foot-altitude photography, and 13 hours for the 10,000-foot-altitude photography.

The interpreter was able to reach a conclusion as to the type of soils observed in the area when halfway through the study of the 20,000-foot photography. The predominant soil is silt with some sand ridges scattered throughout the test site. The conclusion that the soil is silt was reached through an analysis of the pattern elements recorded on the data format. The principal reason that the soil types were detected and recognized in the 20,000-foot-altitude photographs is that the gully shapes and important pattern elements were detectable in photographs taken at that altitude. Work on this study by Professor Mintzer has been completed and is reported in reference 19.

24. <u>Foreign Developments in the Use of Aerial Color Photography.</u>

a. Recent work in the use of aerial color photography has been reported by Mott (20) at a technical meeting of The Photogrammetric Society, London, England. He describes tests in Hong Kong, the Middle East, the Far East, and Asia, with panchromatic, color, and Ektachrome Infrared photography with similar conclusions reached in reference 18 by Anson. Mott reports that for forestry and vegetation studies color is superior to black and white photography, that Mikhailov (1961), USSR,

reports the ages of trees are sometimes identifiable on false color photography (spectrazonal). Mr. Rees of the Directorate of Overseas Surveys reporting on work in Malawi, Africa, stated that "compared with panchromatic, Aerial Ektachrome:

(1) gives a quicker and clearer understanding of the land use pattern.

(2) enables one to identify ground features more quickly and positively.

(3) permits greater differentiation within the land use patterns."

b. Further work in this area has been reported by Welch (21) of the Department of Geography, University of Glasgow, Scotland, in a study of the Breidamerkur Glacier, Iceland. Welch reported that Aerial Ektachrome, Ektachrome infrared, panchromatic, and black and white infrared photography was flown over the Breidamerkur Glacier in August 1965 at 8,000 feet using an RC-8 camera. His conclusions were the following: "It has been found that Aerial Ektachrome possessed the best all-around interpretation qualities with definite advantages for:

(1) the delineation and identification of water bodies, particularly in the separation of silt-laden water bodies from clear ponds and streams.

(2) distinguishing between bedrock, gravels and soils.

(3) the identification and classification of landforms, e.g. moraines, eskers, and ice-scored features.

(4) studying glacier surface features such as streams, crevasse patterns and debris."

These effects were caused by tonal range and brightness in the color photography that is superior to the rendition in panchromatic photography.

IV. DISCUSSION

25. Reporting Period. Research in the fields of aerial color photography was begun by the author in late 1964, at which time events in both Government and industry began to move ahead rapidly in order to provide a reliable system for recording and displaying the differential color hues of photographed terrain. The cutoff date for material to be included in this report was 1 July 1967, but the state-of-the-art is still expanding.

26. Aerial Cameras. The aerial cameras used in this study, the Wild Heerbrugg RC-8, the Fairchild KC-4, and the Zeiss RMK A 15/23, are standard precision mapping cameras whose performance has been proven in the field. Other cameras are under development by other industrial organizations.

27. Processing Equipment. Processing equipment including color printers have also been tested by industry. Some color printers and processors are now ready but have not yet been released for public sale and use. This equipment is approaching field utility in simplicity, reliability, and ruggedness as well as logistic demands.

28. Application of Color Photography to Specific Requirements. The value of aerial color photography has been recognized for interpretations and mapping by many of the Government agencies which have used panchromatic black and white photography in the past. New uses are being continually developed as the state-of-the-art advances; for example, the University of Kansas has employed color coded photography as a means of discriminating densities in radar return representations (22).

29. American Society of Photogrammetry Field Tests. A valuable function of the American Society of Photogrammetry field tests has been to furnish qualitative and quantitative data on the actual performance of cameras and emulsions in the specific extraction of terrain data. An additional field test, conducted by the U. S. Naval Oceanographic Office in March 1967 at Key West, Florida (Fig. 46), has not been reported upon because of incomplete test results (23). Identical cameras that were employed in the Phoenix, Arizona, test were used in the Key West test, as well as the same emulsions and aircraft. The test was primarily designed to determine the water penetration of color, false color, and panchromatic film into the offshore waters of the Boca Chica Naval Air Station. The test range, $4\frac{1}{2}$ miles long, extended seaward from Boca Chica Key to Middle Sambo Reef with water depths from 0 to 70 feet. Color panels (red, yellow, and white), resolution panels, and gray scale panels were emplaced onshore in the

flight line. Smaller color panels, 10 by 30, 20 by 30, and 40 by 30 feet, were placed at different depths around the reef. Flights were made at 2,500, 5,000, 10,000, 20,000, and 30,000 feet with all three precision cartographic cameras operating simultaneously. Ambient light readings on the ground were made of the gray scale panels during the flight, as well as underwater reflected light readings of the bottom at the offshore test site. Preliminary examination of the photography has shown successful color and false color imagery was obtained. Excellent water penetration which was not anticipated, was obtained with the false color film (Ektachrome Infrared), indicating a knowledge gap regarding performance of this material (Fig. 46).

30. Present State-of-the-Art Summary. Although there is substantial information on aerial color photography being developed at the present time, this report is confined to unclassified work being done in Government agencies. The present state-of-the-art in hardware for the collection and processing of aerial color photography is adequate for specific, planned tasks. To some extent, the hardware is ahead of designed uses for aerial color photography. Operational systems for the Defense Department, in the same sense that they are presently available for panchromatic black and white aerial photography, do not exist for color photography. Special missions are possible but not frequent.

31. Trends. Studies and investigations of aerial color photography have focused attention on the composition of reflected energy for panchromatic black and white recording, infrared recording, and radar imagery recording. There is a greater awareness that the whole spectrum, both visible and invisible, should be investigated with closer attention being paid to the unique characteristics of the energy response which reaches the recording camera whatever emulsion is used to make the record. This can materially improve standard black and white, black and white infrared, and multiband (spectrazonal) photography in the future, as well as standard color photography.

32. Research and Development Required to Advance State-of-the-Art.

a. Advanced camera systems with apochromatic lenses which will fully correct for the maximum spectrum range should be studied.

b. Thin film filters to remove interfering effects of haze, dust, and moisture particles should be studied.

c. A complete and thorough Government testing program without bias to any manufacturer or product should be initiated. This

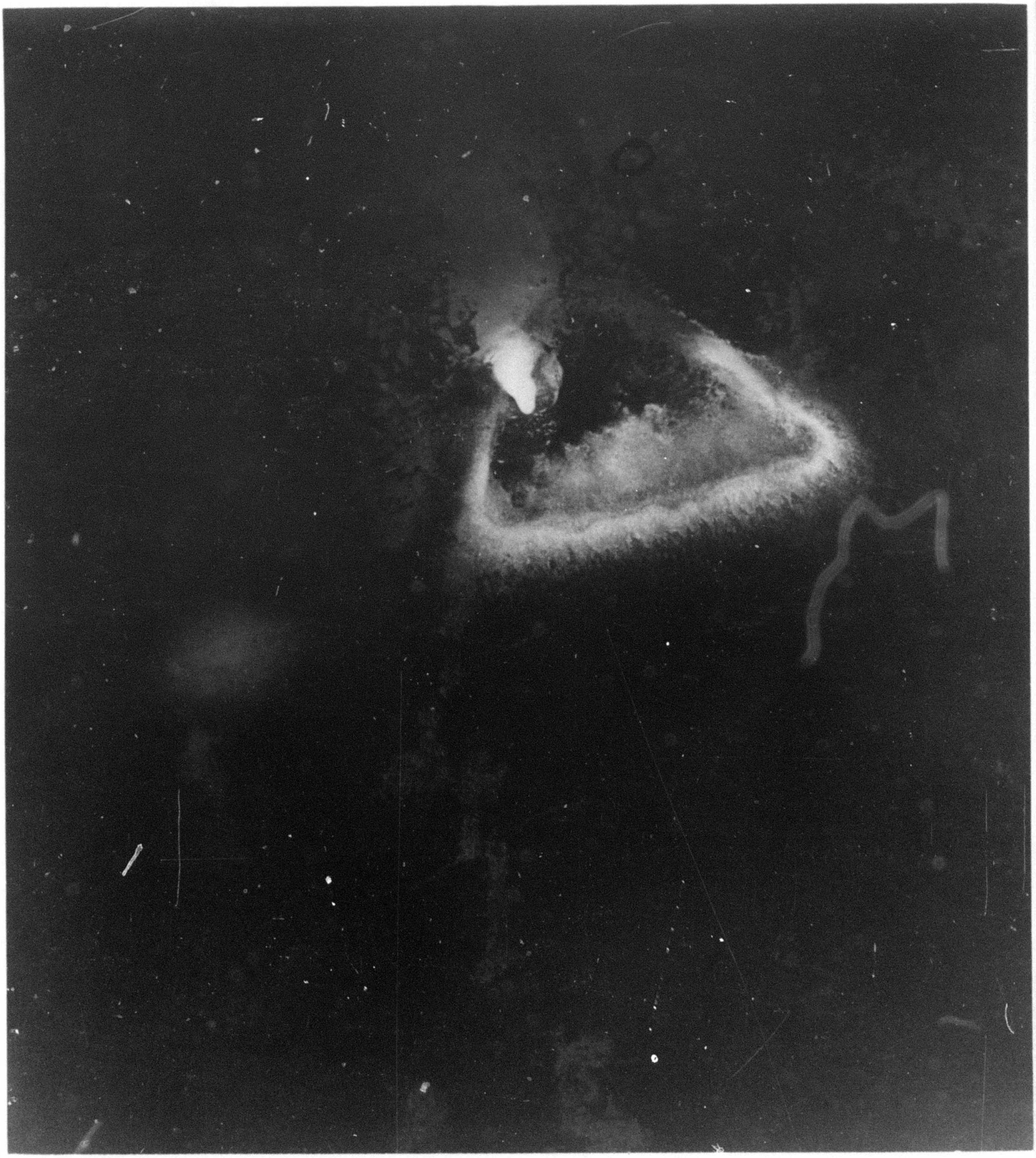

Fig. 46. Middle Sambo Reef off Key West, Florida.
(U. S. Air Force photograph.)

cannot be left to industry or professional societies and is Government's responsibility.

V. CONCLUSIONS

33. Conclusions. It is concluded that the state-of-the-art in aerial color photography is adequate for obtaining satisfactory military photographs provided cameras and emulsions are carefully selected for the mission.

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13. ABSTRACT

The utility of aerial color photography for studies in the fields of geology, geography, archaeology, landforms, range management, target detection, highway planning, and hydrology has been recognized by those who are working in aerial photography; however, the usefulness of color has not been determined adequately for Military Geographic Intelligence. This report is a summation of research into the status of aerial color photography in several Government agencies, and its application to specific problems.

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